सत्यमेव जयते

STATUS PAPER ON COARSE CEREALS

(Sorghum, Pearl millet, Finger millet, Small millets, Maize and Barley)

Kisan Ki Unnati - Desh Ki Pragati

Directorate of Millets Development
Department of Agriculture & Cooperation
Ministry of Agriculture
Government of India
March, 2014

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Ministry of Agriculture,
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March, 2014

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भारत सरकार
कृषि मंत्रालय
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FOREWORD

Coarse cereals are traditionally grown in resource poor agro-climatic regions of the country. Coarse cereals include Sorghum, Pearl millet, Ragi, Small millets, Maize and Barley.

In the present scenario, demand for coarse cereals is declining due to change in food habits and the longer time required for coarse cereal food preparation as compared to fine cereals. The consumption of these food items has also been traditionally restricted mainly to growing areas.

Coarse cereals are known for nutria-rich content and having characteristics like drought tolerance, photo-insensitivity and resilient to climate change etc. These crops also offer a good potential in food processing industry and as a promising exportable commodity.

The major coarse cereals growing states i.e. Rajasthan (26%), Maharashtra (21.4%), Karnataka (13.2%), Uttar Pradesh (7.3%), Madhya Pradesh (6.6%) and Gujarat (5.5%) have about 90% area of total coarse cereals in the country.

To promote cultivation and consumption of millets, Government of India introduced Scheme on "Initiative for Nutritional Security through Intensive Millet Promotion (INSIMP)" in 2011-12. These crops have been included as an integral part of National Food Security Mission during XII Plan. Coarse cereals have also been included in Public Distribution System at subsidized rates after introduction of National Food Security Act.

The status paper on Coarse Cereals (Sorghum, Pearl millet, *Ragi,* Small millets, Maize and Barley) is compiled by the Directorate of Millets Development, Jaipur in consultation with institutes i.e. Directorate of Sorghum Research (DSR), Directorate of Maize Research (DMR), Directorate of Wheat Research (DWR), Project Coordinator (Pearl Millet) and Project Coordinator (Small Millets).

I hope it would be helpful for students, researchers, policy makers, academicians, industry & trade associated with the production, processing and value addition.

I congratulate Shri Sanjay Lohiya, Joint Secretary (Crops) and Dr. D.P. Malik. Additional Commissioner (Crops) for bringing out this report. I also congratulate Dr. M.N. Singh. Director (Incharge), Dr. Subhash Chandra, Joint Director and Shri A. Ansari. Statistical Investigator from Directorate of Millets Development, Jaipur for compiling this document.

(J.S. Sandhu)

Place : New Delhi
Date : 18 February, 2014

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PREFACE

The Directorate of Millets Development, a subordinate office of the Ministry Agriculture, Department of Agriculture & Cooperation (DAC), is entrusted with the responsibility of monitoring of millets development programmes at National level and have liaison with Indian Council of Agriculture Research Institutions, like Directorate of Sorghum Research (DSR), Hyderabad; Directorate of Maize Research (DMR), New Delhi; Directorate of Wheat Research (DWR), Karnal; All India Coordinated Pearl Millet Improvement Project (AICPMIP), Mandor, Jodhpur and All India Coordinated Small Millets improvement Project (AICSMIP), GKVK, Bengaluru. These Institutions have provided a large number of hybrids/varieties, which have contributed significantly in productivity improvement of these crops. The private sector has a major stake in development and supply of seed of hybrids of sorghum, pearl millet & maize and also in utilization of coarse grains in various value added food products.

In order to have an effective linkage between research and technology transfer, a programme on Front Line Demonstration (FLD) was launched by the Ministry of Agriculture in 1995-96. Under this programme, newly released cultivars and improved crop production technologies are demonstrated by the Agricultural Scientists of ICAR and SAUs on farmers' fields. For promotion of millets/coarse cereals in the country, a programme of "Initiative of Nutritional Security through Intensive Millets Promoion (INSIMP)" was launched with effect from 2011-12 to promote cultivation and consumption of millets based food products. Coarse cereals are being included in NFSM during 12th Five Year Plan, which would be implemented w.e.f. 2014-15. Nutri-rich varieties coarse cereals are also being promoted under Nutri-Farm Programme which was started in 2013-14.

I am grateful to Shri Sanjay Lohiya, Joint Secretary (Crops) for his initiative, guidance and encouragement in bringing out this publication. This paper would create valuable inputs for use of all the stakeholders who are concerned about for the sustainable development of coarse cereals in the country. I am also grateful to Smt. Reena Saha, Director (Crops), Dr. D.P. Malik, Additional Commissioner (Crops), Shri S.K. Dalal, Ex-Additional Commissioner, DAC, Dr. J.P. Singh, Ex-Director, Directorate of Millets Development, Dr. B.B. Singh & Er. Shamsher Singh, National Consultants of NFSM and Dr. Sain Das, Ex-Director, DMR for their valuable suggestions in bringing out this publication.

The information provided by the State Department of Agriculture; DSR, Hyderabad; DMR, New Delhi, DWR, Karnal, AICPMIP, Mandor, Jodhpur and AICSMIP, Bengaluru is gratefully acknowledged.

I am grateful to my colleague Dr. Subhash Chandra, Joint Director and Shri Amaluddin Ansari, Stastical Investigator of the Directorate for their contribution in this endeavour.

Place : Jaipur
Date : 18th Feb., 2014

(Dr. M.N. Singh)
Director (Incharge)

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Coarse Cereals

COARSE CEREALS

India with its diversified agricultural assets in terms of soil, rainfall and climate has abundant crop diversity. Owing to their several drought tolerance characteristics, their cultivation in drought prone areas for providing food for human consumption, feed & fodder for animal and poultry, use as fuel and industrial uses are in common. During drought condition, it helps in generating employment in low rainfall areas where other alternative crops are limited and these crops are used as a contingent crop. As an assured source of income, these coarse cereals offer a better role during distress environment.

A variety of coarse cereals are grown throughout the country in different ecology, agro-climatic condition, but mostly as rainfed crop. Sorghum, pearl millet, maize, barley, finger millet and several small millets such as kodo millet, little millet, foxtail millet, proso millet and barnyard millet together called coarse cereals. Sorghum, pearl millet, finger millet, maize and small millets (barnyard millet, proso millet, kodo millet and foxtail millet) are also called nutri-cereals.

Globally, average production of coarse grains is estimated to be about 1130.25 million tonnes during 2007-2011 and India contributed 3.6% (40.19 million tonnes) in global production of coarse grains and India ranks 4th after USA, China & Brazil. More than 75% of the world coarse grains are produced in USA, China, India, Russian Federation, Brazil, Nigeria, Niger, Mexico, Sudan, Ukraine, Ethiopia, Australia, Poland, Canada, Argentina, Tanzania, Spain and France (FAOSTAT 2011). In India, yield of coarse grains is about 1433 kg/ha as compared to world average yield of 3512 kg/ha. The highest productivity of 8946 kg/ha was recorded in USA (**Table-1**).

Table-1: **Mean area, production and yield of coarse grains (2007-2011)**

SI.No.	Country	Area (Lakh ha.)	Production (Lakh tonnes)	Yield (Kg/ha)
1	United States of America	375.63 (11.7)	3360.45 (29.7)	**8946**
2	China	346.94 (10.8)	1786.92 (15.8)	5151
3	India	280.49 (8.7)	401.85 (3.6)	1433
4	Russian Federation	152.23 (4.7)	313.13 (2.8)	2057
5	Brazil	146.40 (4.5)	570.62 (5.0)	3898
6	Nigeria	146.01 (4.5)	210.13 (1.9)	1439
7	Niger	96.95 (3.0)	41.75 (0.4)	431
8	Mexico	89.25 (2.8)	289.80 (2.6)	3247
9	Sudan (former)	88.61 (2.8)	47.64 (0.4)	538
10	Ukraine	79.40 (2.5)	242.93 (2.1)	3060
11	Ethiopia	75.24 (2.3)	119.39 (1.1)	1587
12	Australia	65.13 (2.0)	120.54 (1.1)	1851
13	Poland	59.27 (1.8)	181.99 (1.6)	3070
14	Canada	58.35 (1.8)	245.22 (2.2)	4202
15	Argentina	46.80 (1.5)	265.35 (2.3)	5670
16	United Republic of Tanzania	42.71 (1.3)	53.76 (0.5)	1259
17	Spain	41.52 (1.3)	146.09 (1.3)	3519
18	France	39.58 (1.2)	288.59 (2.6)	7292
19	Indonesia	39.57 (1.2)	166.40 (1.5)	4205
20	Turkey	38.92 (1.2)	118.12 (1.0)	3035

Table-1 contd.....

Sl.No.	Country	Area (Lakh ha.)	Production (Lakh tonnes)	Yield (Kg/ha)
21	Burkina Faso	37.25 (1.2)	36.66 (0.3)	984
22	Germany	35.28 (1.1)	215.77 (1.9)	6116
23	Mali	34.84 (1.1)	36.86 (0.3)	1058
24	Romania	30.32 (0.9)	96.85 (0.9)	3194
25	South Africa	28.10 (0.9)	115.19 (1.0)	4099
26	Philippines	26.07 (0.8)	68.10 (0.6)	2612
27	Mozambique	23.57 (0.7)	21.15 (0.2)	897
28	Morocco	23.35 (0.7)	23.98 (0.2)	1027
29	Chad	23.14 (0.7)	17.88 (0.2)	773
30	Kenya	21.71 (0.7)	31.64 (0.3)	1457
31	Kazakhstan	21.66 (0.7)	30.31 (0.3)	1399
32	Zimbabwe	20.03 (0.6)	11.53 (0.1)	575
33	Belarus	18.79 (0.6)	58.59 (0.5)	3118
34	Pakistan	18.49 (0.6)	42.30 (0.4)	2288
35	Iran	17.45 (0.5)	47.89 (0.4)	2745
	World	**3218.43 (100)**	**11302.53 (100)**	**3512**

Source: FAOSTAT 2011

In India, coarse cereals are grown over an area of 27.67 million ha (22% of total food grains), with a production of 39.95 million tonnes during 2007-08 to 2011-12 and contributed about 17% to national food basket. More than 90% coarse cereals are produced in Rajasthan, Maharashtra, Karnataka, Uttar Pradesh, Madhya Pradesh, Gujarat, Andhra Pradesh, Haryana, Bihar and Tamil Nadu States (**Table-2**).

Table-2: State-wise normal area, production and yield of total coarse cereals (Average of 2007-08 to 2011-12)

Sl.No.	States	Area (Lakh ha.)	Production (Lakh tonnes)	Yield (Kg/ha)
1	Rajasthan	71.93 (26.0)	67.82 (17.0)	943
2	Maharashtra	59.33 (21.4)	65.61 (16.4)	1106
3	Karnataka	36.45 (13.2)	67.50 (16.9)	1852
4	Uttar Pradesh	20.23 (7.3)	31.78 (8.0)	1571
5	Madhya Pradesh	18.34 (6.6)	21.89 (5.5)	1194
6	Gujarat	15.11 (5.5)	20.12 (5.0)	1331
7	Andhra Pradesh	12.45 (4.5)	41.96 (10.5)	3370
8	Haryana	7.42 (2.7)	13.15 (3.3)	1772
9	Bihar	6.84 (2.5)	15.78 (4.0)	2306
10	Tamil Nadu	6.69 (2.4)	17.27 (4.3)	2582
11	Jammu & Kashmir	3.54 (1.3)	5.50 (1.4)	1556
12	Himachal Pradesh	3.28 (1.2)	7.26 (1.8)	2215
13	Chhattisgarh	2.85 (1.0)	2.08 (0.5)	728

Table-2 contd.....

Sl.No.	States	Area (Lakh ha.)	Production (Lakh tonnes)	Yield (Kg/ha)
14	Uttarakhand	2.58 (0.9)	3.30 (0.8)	1280
15	Jharkhand	2.47 (0.9)	3.09 (0.8)	1250
16	Odisha	1.81 (0.7)	2.50 (0.6)	1387
17	Punjab	1.60 (0.6)	5.55 (1.4)	3473
18	West Bengal	1.07 (0.4)	3.56 (0.9)	3328
19	Nagaland	0.81 (0.3)	1.27 (0.3)	1559
20	Arunachal Pradesh	0.66 (0.2)	0.82 (0.2)	1236
21	Sikkim	0.48 (0.2)	0.72 (0.2)	1509
22	Assam	0.25	0.17	674
23	Meghalaya	0.20	0.28	1423
24	Manipur	0.12	0.24	2005
25	Mizoram	0.08	0.09	1049
26	Delhi	0.07	0.09	1285
27	Kerala	0.03	0.02	626
28	Tripura	0.03	0.03	1171
29	D & N Haveli	0.02	0.02	1162
30	Daman & Diu	0.01	0.01	1857
31	Goa	Neg.	0.01	2032
32	A & N Islands	Neg.	0.01	2864
33	Others	0.55	0.79	1426
	All India	276.73	399.50	1444

Source: DES, DAC.

The area of coarse cereals except maize has declined after inception of green revolution and the area of coarse cereals reduced from 44.35 million ha in 1965-66 to 26.42 million ha in 2011-12 i.e. 40% (**Table-3**). The major area declined under small millets (82%), barley (76%) Jowar (65%), Finger millet (56%) and Bajra (27%). However, area under maize is increased (83%) from 4.8 million ha to 8.78 during the same period due to better demand of maize for feed, fodder and industries uses. Despite 40% area reduction of coarse cereals, the production has almost doubled during 2011-12 as compared to 1965-66. This is because of crop improvement viz; high yielding varieties/hybrids, package of practices, etc. The production of coarse cereals has sustained due to use of hybrid/high yielding varieties, providing technical/extension services, timely availability of credit support by banks.

Table-3: Crop specific Area, production and productivity of coarse cereals.

Sl.No.	Crops	1955-56	1965-66	1975-76	1985-86	1995-96	2005-06	2011-12
Area in Lakh ha								
1	*Jowar*	173.60	176.80	160.90	161.00	113.30	86.67	62.45
2	*Bajra*	113.40	119.70	115.70	106.50	93.20	95.81	87.77
3	*Ragi*	23.07	26.96	26.30	24.01	17.74	15.34	11.76
4	Small millets	53.35	45.64	46.72	31.55	16.62	10.64	7.99
Total millets		**363.42**	**369.10**	**349.62**	**323.06**	**240.86**	**208.46**	**169.97**
5	Barley	34.18	26.40	28.02	13.69	8.24	6.30	6.43
6	Maize	37.00	48.00	60.30	58.00	59.80	75.88	87.82
Total coarse cereals		**434.60**	**443.50**	**437.94**	**394.75**	**308.90**	**290.64**	**264.22**

Table-3 contd.....

Sl.No.	Crops	1955-56	1965-66	1975-76	1985-86	1995-96	2005-06	2011-12
Production in Lakh tones								
1	*Jowar*	67.26	75.81	95.04	101.97	93.27	76.30	60.06
2	*Bajra*	34.30	37.52	57.36	36.64	53.81	76.84	102.76
3	*Ragi*	18.46	13.27	27.97	25.18	25.01	23.54	19.29
4	Small millets	20.70	15.55	19.24	12.17	7.79	4.72	4.52
Total millets		**140.72**	**142.15**	**199.61**	**175.96**	**179.88**	**181.40**	**186.63**
5	Barley	28.16	23.82	31.92	19.62	15.10	12.21	16.19
6	Maize	26.02	48.23	72.56	66.44	95.34	147.10	217.59
Total coarse cereals		**194.90**	**214.20**	**304.09**	**262.02**	**290.32**	**340.71**	**420.41**
Productivity in Kg/ha								
1	*Jowar*	387	429	591	633	823	880	962
2	*Bajra*	302	314	496	344	577	802	1171
3	*Ragi*	800	492	1064	1049	1410	1534	1641
4	Small millets	388	341	412	386	469	443	565
Total millets		**387**	**385**	**571**	**545**	**747**	**870**	**1098**
7	Barley	824	902	1139	1434	1834	1938	2516
8	Maize	704	1005	1203	1146	1595	1938	2478
Total Coarse cereals		**639**	**675**	**1041**	**1323**	**1703**	**1968**	**1591**

The focus of green revolution was on high-yielding and high input utilization crops such as wheat and rice to meet the demand of food security resulted in policies favouring their cultivation. Further, these crops received research, extension and market support. Thus, on the supply side, there was a shift in area under cultivation from coarse cereals to fine cereals (rice & wheat).

Poor policy support for coarse cereals on the one hand favourable policies for the cultivation of oilseeds such as sunflower and soybeans and cash crops such as cotton on the other hand became more profitable, driven by yield increases and higher prices spurred by growing consumer demand. This has resulted in serious imbalances in the demand and supply of various agricultural commodities in the country.

On the consumption side, in urban areas, an increase in incomes, change in consumer tastes and preferences, husband and wife jobs, advent of fast food chains and ready-to-eat food products, easily availability to rice and wheat on subsidized rate through PDS, social status attached to fine cereals, the penetration of diversified value-added products from rice and wheat and the ease of preparation and short cooking time for them have resulted in their increased consumption. In contrast, longer cooking times, difficulty in preparation and lack of value addition & value-added products contributed to a decline in the consumption of millets. Extension efforts towards the cultivation of millets were relegated and coupled with market failure; which led to a failure to capture the nutritive value of millets. Due to change of food habits and urbanization, there is growing evidence of chronic, malnutrition and under nutrition. The main reasons is shifting consumption pattern from a balance diet to inadequate and fatty diet due to change of food habit and non-availability of millets. The wide spread prevalence of nutritional deficiency such as protein, vitamin A, iron and iodine as prevalent among children and women. Thus the nutritious cereals are comparable or even superior to fine cereals, and therefore, the inclusion of these cereals would definitely ensure the fulfillment of dietary requirement.

These cereals can act as a shield against nutritional deficiency disorders and provide for nutritional security. The anemia (iron deficiency), B-complex vitamin deficiency), pellagra (nicotinic and deficiency) can be effectively tackled intake of less expensive but nutritionally rich food grains like millets.

Nutritive values of coarse cereals: Proximate composition and nutritive value of millets is given in **Table-4**. The millet grains contains substantially high amount of fat, fibre and minerals in comparison to fine cereals like wheat and rice. The protein content in millets like *Jowar* (10.4), *Bajra* (11.6), Proso millet (12.5), foxtail millet (12.3) and barnyard millet (11.6) is comparable with wheat (11.8) and much higher than rice (6.8). Though the finger millet contains lesser protein (7.3), but it is rich in mineral matter and calcium in comparison to wheat and rice. All the millets contain more fibre than fine cereals. Particularly, the small millets namely barnyard millet (14.7), *Kodo* millet (9) little millet (8.6) and foxtail millet (8.0) are the richest in fibre in comparison to wheat (1.2) and rice (0.2). Therefore, millets are now being pronounced as “Miracle grains/ *Adbhut Anaj* and nutria-cereals”.

Table-4: Proximate composition of coarse cereals and fine cereals (Per 100 g)

Commodity	Protein (g)	Carbohy-drates (g)	Fat (g)	Crude fibre (g)	Mineral matter (g)	Calcium (mg)	Phosp-horus (mg)
Sorghum	10. 4	72. 6	1. 9	1. 6	1. 6	25	222
Pearl millet	11. 6	67. 5	5. 0	1. 2	2. 3	42	296
Finger millet	7. 3	72. 0	1. 3	3. 6	2. 7	344	283
Proso millet	12. 5	70. 4	1. 1	2. 2	1. 9	14	206
Foxtail millet	12. 3	60. 9	4. 3	8. 0	3. 3	31	290
Kodo millet	8. 3	65. 9	1. 4	9. 0	2. 6	27	188
Little millet	8. 7	75. 7	5. 3	8. 6	1. 7	17	220
Barnyard millet	11. 6	74. 3	5. 8	14. 7	4. 7	14	121
Barley	11.5	69.6	1.3	3.9	1.2	26	215
Maize	11.5	66.2	3.6	2.7	1.5	20	348
Wheat	11. 8	71. 2	1. 5	1. 2	1. 5	41	306
Rice	6. 8	78. 2	0. 5	0. 2	0. 6	10	160

Source: National Institute of Nutrition (N IN), Hyderabad.

Fodder values: Livestock is a backbone of agrarian economy of arid and semi-arid regions wherein the millets are largely grown. These regions quite often experience droughts. Many traditional as well as improved methods have been developed by the farmers to make use of preserved fodder crops during drought situations. The livestock enterprise in India largely depends on agricultural crop residue and by products of food grains/oilseeds etc. The cultivation of Millets like sorghum and pearl millet in some Northern States like Haryana, Punjab and Western UP is primarily done for fodder purposes. A number of varieties/hybrids of sorghum and pearl millet have been developed particularly for fodder purposes.

The recent studies to mitigate emission of green house grass through biological nitrification substances (BNI) has also reveals that sorghum and pearl millet have BNI ability in root exudates, which could play a vital role in mitigation the impact of global warming by regulating the emission of N_2O to atmosphere.

Uses of coarse cereals:

(a) Coarse cereals uses as feed, fodder, fuel, value added products and fast food products are given as under:-

Crops	Food products	Industrial products
Sorghum	*Roti*, *ugali*, popped sorghum, malt food, snack/roasted mix grains.	Malting, high fructose syrup, starch, *Jaggery*, bakery, value added products for diabetics poultry and animal feed.
Pearl millet	*Roti*, *ugali*, fermented food products, pizza, roasted mix grains.	Brewing/malting, starch, bakery, poultry and animal feed.
Finger millet	*Roti*, dumpling, popped millet, malt-food.	Malting/brewing, baby foods, bakery and food for diabetics.
Small millets	*Roti*, cooked cereals.	Value added food for devotees (Barnyard millet), Feed, value added food products for diabetics.
Maize	*Chapaties,* ladoo, halva, kheer, sev, mathi, *popped corn,* etc.	Brewing, starch, bakery, poultry and animal feed, bio-fuel.
Barley	*Roti, Sattu.*	Malting/brewing, Distillation, Energy drinks/ confectionery, pharmaceuticals.

(b) Contingent planning: When monsoon get delayed, coarse cereals is a best fit for contingent planning because of their photo insensitivity, drought resistant and earliness.

(c) Source of feed: Increase in income is resulting in an increase in demand for meat, milk and other animal products. The demand for coarse cereals for animal and poultry feed is also increasing. In India, feed requirements are met from waste food grains in general and made especially from coarse cereals. Maize is the preferred carbohydrate source in poultry feed.

Milestones of coarse cereals development in India: The Government has given a due priority to both research and development of these crops. The important initiatives taken in this regards are summarized as under:-

Year	Activity
1952	Setting up of “Grow More Food Enquiry Committee”.
1955	Visit of Dr. E.J. Wellhausen & U.J. Grant of Rockfeller Foundation.
1964	**Release of first public bred Sorghum Hybrid “CSH-1”.**
1965	Setting up of “All India Coordinated Millets Improvement Project” by ICAR.
1965	**Release of first public bred pearl millet Hybrid “HB-1”.**
1967	Launching of “HYVP” in respect of five cereals viz; Rice, Wheat, Maize, Sorghum and Pearl millet by GOI.
1969	Setting up of “All India Coordinated Sorghum Improvement Project” by ICAR.
1971	Setting up of the Directorate of Millets Development by GOI.

Year	Activity
1972	Establishment of the International Crops Research Institute for the Semi Arid Tropics with mandated crops of **Sorghum, Pearl millet,** Chick pea, Pigeon pea and Groundnut.
1974	Launching of Central Sector Scheme on "Minikit Programme of Pre-release varieties of Coarse cereals."
1979	Launching of "Demonstrations of intensive cultivation of Coarse Cereals in ST/SC areas".
1982	Inclusion of location specific released varieties/hybrids under Central Sector Scheme on "Minikit Programme of Coarse cereals".
1985	Setting up of "All India Coordinated Pearl millet Improvement Project" by ICAR
1986	Setting up of "All India Coordinated Small Millets Improvement Project" by ICAR.
1987	Launching of Centrally Sponsored "Special Food Production Programme of "Maize".
1987	Setting up of "National Research Centre for Sorghum (NRCS) by ICAR.
1994	Launching of Centrally Sponsored "Integrated Cereals Development Programme in Coarse Cereals based Cropping System".
1995	Introduction of Front Line Demonstration (FLD) programme by DAC.
1995	Accelerated Maize Development Programme.
2000	Integrated Schemes of Oilseeds, Pulses, Oil palm and Maize
2000	Visit of FAO Mission on Special programme for Food Security from 19-29th November, 2000
2000	First National Seminar on "Sustainable Development of Coarse cereals" on 7-8th February, 2000 at the State Institute of Agricultural Management Durgapura, Jaipur.
2000	Introduction of Macro-Management Mode (MMM) of Agriculture to provide greater flexibility in programme implementation to the State Government.
2001	Second National Seminar on "Outlook of Coarse cereals in the new millennium" on 27-28th November, 2001 at Krishi Bhavan, Gandhi Nagar, Gujarat.
2003	Up gradation of computer facilities in Crop Development Directorate under "DACNET" project of Department of Agriculture and Cooperation.
2004	Third National Seminar on "Millets: Research and Development Future Policy Options in India" on 11-12th March, 2004 at Mandor, Jodhpur.
2010	Fourth National Seminar/Brain storming on Millets at Hyderabad.
2011	Initiatives for Nutritional Security through Intensive Millets Promotion (INSIMP)
2011	Accelerated Fodder Development Programme (AFDP)
2013	Inclusion of coarse cereals under Food Security Bill
2013	Inclusion of coarse cereals under National Food Security Mission during XII Plan w.e.f. 2014-15

Crop Development Programmes on Coarse cereals

In order to provide farmers' reaction of new varieties/hybrids to the researchers, **"Central Sector Scheme on Minikits Programme of Pre-release varieties of Coarse Cereals"** was launched during 1974. After successful results of Minikit programme, Government of India launched a **"State Level Training Programme on Coarse cereals for propagation of recent Production Technologies"** among extension workers as a component of ongoing "Central Sector Scheme of Minikit Programme" during 1976. Further, in order to provide technical backstopping at the door steps of ST/SC farmer and a social safety net to economically backward farmers "Demonstrations of Intensive Cultivation of Coarse cereals in ST/SC Areas" was launched during 1979 under ongoing "Central Sector Scheme of Minikit Progrmme". A new component of "Minikit Programme of released cultivars" was also included under ongoing Central Sector Scheme of Minikit Programme in 1982.

A Centrally Sponsored "Special Food Production of Maize" was launched in 1987 later included millets. Before 1990s, focus was on individual crop in identified districts. Thereafter, to follow the cropping system approach, Centrally Sponsored scheme on "Integrated Cereals Development Programme in Coarse Cereals based Cropping System Areas (ICDP-CC)" was launched in 1994 in major coarse cereals growing States namely; Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan & Sikkim. From 2000 the ICDP-CC was subsumed under Macro Management Mode of Agriculture. Maize was excluded from ICDP (CC) and a separate programme namely; Accelerated Maize Development Programme was launched w.e.f. 1995-96 as mission mode approach to enhance the production and productivity of maize. Besides, a sub-programme on maize based cropping systems for food security in India under GOI-UNDP Food Security programme being fully funded by UNDP, for implementation in 9 villages of six districts in three States viz: Bihar, Rajasthan & Uttar Pradesh for four years, w.e.f. 1999-2000, was also implemented to provide stimulus effect on the AMDP for attaining GOI's objective of increasing the production & productivity of Maize in the country. Thereafter, maize crop was included under Integrated Schemes of Oilseeds, Pulses, Oil palm and Maize (ISOPOM) from IX Plan.

A Centrally Sponsored Scheme (CSS)–Macro Management of Agriculture was evolved by integrating 27 CSS including Integrated Cereals Development Programmes in Coarse cereals based Cropping Systems Areas (ICDP-CC). This scheme aimed at development in agriculture through work plan prepared by the States. The Scheme provided flexibility to the States to develop and pursue activities on the basis of their location specific needs. The States had flexibility within given parameters to select schemes of their choice out of 27 schemes and their component and include them in their Work Plan. The States were also free to include new/innovative interventions in the Work Plan provided; it was not covered under any other scheme of the Central Government or was not part of any ongoing State schemes. The ceiling for new initiatives was increased from existing 10% to 20% of the total allocation. Schemes also had a provision for utilization of at least 33% funds for small, marginal and women farmers.

The approved pattern of assistance under the Schemes was in the ratio of 90:10 for the Centre and the State respectively except North-Eastern States, who were provided 100% Central assistance. Assistance to the States/UTs was provided as 100% Grant-in-aid. All States were eligible to receive assistance under MMA Scheme.

To demonstrate the improved package of practices/technologies and newly released cultivars on farmers' field, Front Line Demonstrations (FLDs) on coarse cereals- a direct funded component of Macro Management of Agriculture was also implemented through concerned ICAR center/ institute.

A National brainstorming Workshop on Millets was held at NIRD, Hyderabad during October, 2010. Based on the recommendations of the Workshop a committee headed by Agriculture Commissioner was constituted to give the modalities of promotion of millets. After recommendation of the committee and in order to promote cultivation and consumption of millet based food products, the Government announced an allocation of Rs. 300 Crore in 2011-12 and Rs. 175 crore in 2012-13 under Rashtriya Krishi Vikas Yojana (RKVY) for promotion of nutritional security.

Accordingly, a programme of "Initiative for Nutritional Security through Intensive Millets Promotion (INSIMP)" was launched during 2011-12. This scheme aims to demonstrate the improved production and post-harvest technologies in an integrated manner with visible impact to catalyze increase in production of millets in the country. Besides increasing production of millets, the Scheme through processing and value addition techniques is expected to generate consumer demand for millet based food products. The scheme is implemented in 16 States. Arunachal Pradesh, Andhra Pradesh, Chhattisgarh, Gujarat, Haryana , Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Rajasthan , Tamil Nadu, Uttar Pradesh, Uttrakhand, West Bengal and Sikkim.

Under the scheme three National Centres of Excellence (CoEs) have been established at CCSHAU, Hissar for pearl millet, at Directorate Sorghum Research, Hyderabad for sorghum and at University of Agriculture Sciences, Bangaluru for small millets. Besides, scheme has also provision for setting up of processing units through Progressive Farmers, Entrepreneurs/NGOs and creation of awareness. There is a also provision for training of selected cluster farmers before sowing season to know about latest crop production technology and use of micro nutrients and fertilizer in their demonstration.

A pilot scheme for establishing Nutri-Farm in districts of the country that are most affected by malnutrition is also under implementation during 2013-14. It envisaged that bio – fortified food crops enriched with critical micro-nutrients would improve their nutritional status of the most vulnerable sections of the population. This programme has been launched in 100 districts of 9 States for cultivation and promotion of micro-nutrients rich cultivars of cereals includes Pearl Millets, Maize and Finger Millets. The objectives are as under:

(i) Demonstration of improved production technology to promote cultivation of Nutri-rich varieties/ hybrids of Pearl Millets, Small Millets and Maize.

(ii) Encouragement of commercial cultivation of specified Nutri-rich crops varieties through cluster approach of farmers.

(iii) Development of supply chain of Nutri– rich produce to vulnerable section of population.

Under this schemes assistance @Rs. 5000/ per ha is provided to the farmers for organizing Demonstration in cluster mode, Rs. 15000/per cluster on food processing and value addition.

Inclusion of coarse cereals under Food Security Bill: The National Food Security Act, 2013 (also **Right to Food Act**) aims to provide subsidized food grains to approximately two thirds of population of the country. Under the provisions of the bill, beneficiaries are to be able to purchase 5 kilograms per eligible person per month of cereals such as rice @ Rs. 3/- per Kg; wheat @ Rs.2/- per Kg and coarse grains (millets) @ Rs.1/- per Kg.

National Food Security Mission: The Programme "Initiative for Nutritional Security through Intensive Millets Promotion (INSIMP), Accelerated Fodder Development progamme and Maize programme has been withdrawn from ISOPOM and included National Food Security Mission as one of the component of during 12th Five Year Plan. NFSM-coarse cereals will be implemented in 182 districts of different States with effect from 1.4.2014. The districts covering 70 % area of the total Coarse Cereals in the State have been selected. Under NFSM-coarse cereals interventions such as Accelerated Crop Production Programme (ACPP), Frontline Demonstrations, distribution of hybrid / certified seed, research support for Value addition and marketing support for millets, etc. are covered.

Special initiatives taken for encouraging the cultivation of coarse cereals

The Government's price policy for agricultural commodities seeks to ensure remunerative prices to growers for their produce with a view to encourage higher investment and production, and to safeguard the interest of consumers by making available supplies at reasonable prices. The price policy also seeks to evolve a balanced and integrated price structure in the perspective of the overall needs of the economy. Towards this end, the Government announces each season Minimum Support Prices (MSPs), for major agricultural commodities and organizes purchase operations through public and cooperative agencies. The Government decides on the support price for various agricultural commodities taking into account the recommendations of the Commission for Agricultural Costs & Prices (CACP), the views of the State Governments and Central Ministries as well as other relevant factors which are considered important for fixation of support prices. Minimum Support Price (MSP) of coarse cereal crops during 2008-09 to 2012-13 is as under:-

Minimum Support Price (MSP) of coarse cereal crops (Rs. per quintal)

Year	Sorghum		Pearl millet	Finger millet	Maize	Barley
	Hybrid	Maldandi				
2008-09	840	860	840	915	840	680
2009-10	840	860	840	915	840	750
2010-11	880	900	880	965	880	780
2011-12	980	1000	980	1050	980	980
2012-13	1500	1520	1175	1500	1175	980

Research needs

On production front large numbers of improved varieties/composites/hybrids have been developed in case of sorghum and pearl millet. A number of varieties are available in case of finger millet. However, in case of small millets the number of varieties under each crop is much lower than major millets. These varieties/hybrids also include resistant varieties/hybrids for biotic and abiotic stress. A number of States, have, however raised their research needs for millets as under:

Andhra Pradesh:

- Location specific varieties/hybrids for millets.
- Drought resistance/tolerant hybrids/varieties.
- Experiment on zero tillage for millets.
- People-centered and people directed research for development of millets farming system.

Haryana:

- Seed setting and maintenance of plant population in pearl millet is an area of concern.

- Development of short duration disease resistant (smut and downy mildew) hybrid of pearl millet.

Karnataka:

- Development of varieties/hybrids for low productive area/low input conditions.
- Development of variety/hybrids with a biotic stress (drought and salinity).
- Enhancing profitability and sustainability of millets through inter-cropping.
- Technologies for in-situ moisture conservation.
- Validation of technology under real farming situations.
- Development of pre-processing machinery for dehusking of small millets.

Madhya Pradesh: Development of drought resistant of varieties and improved production technologies.

Rajasthan:

- Development of varieties/hybrids with better regenerative capacity on reversal of dry spell for harsh environment/drought prone areas.
- Development of short duration (60-70 days) hybrids/varieties tolerant to salt/high temperature.

The ongoing research on "Bio-fortification Research in pearl millet" in ICRISAT and participating Indian centres also indicates a better hope for value addition. Bio-fortification means enrichment/value addition in crop through genetic manipulations. A major thrust is given to bio-fortification under CGIR funded research programme by ICRISAT. A large Indian women population (57% women) has iron deficiency (anemia) and 72% children of 6-59 month age have deficiency of zinc (stunting of growth). The aim of bio-fortification in pearl millet is to develop varieties/hybrids with high iron and zinc content. The preliminary work done so far reveal as under:-

- Availability of genotypes/lines with high iron content (53-125 ppm).
- Availability of genotypes/lines with high zinc content (up to 82 ppm).
- Positive correlation between iron and zinc.
- No correlation between iron/zinc content and grain yield.
- Pre-dominantly additive gene action provides scope for recurrent selection for improvement for iron/zinc content in pearl millet grains.
- Increase in zinc content is also suppressing disease like wilt (*Fusarium spp.)*.

A due priority on research on bio-fortification in small millets, which are rich in minerals and fibres would be of great use in conservation and sustainable cultivation of small millets.

Demand for additional incentive towards conservation of bio-diversity, low water consumption, agro-climatic limitations and high nutritious value of millets is quite often raised in various platforms. The scientific data to support such claim may be generated by All India Coordinated Crop Improvement Projects on Sorghum/Pearl millet/Small millets.

Sorghum
(Jowar)

1. SORGHUM (*Sorghum bicolor* (L.) Moench)

1.1 Introduction

Cultivation of sorghum probably originated in East Central Africa, in or near Ethiopia or Sudan because of the great diversity of types growing in that region. The diversity decreases towards Southern Africa and Asia. Although several of the wild species have been collected in India, there is no evidence of an independent origin of cultivated sorghum in India because the general types grown here are abundant in Africa. In India, sorghum is cultivated during both kharif (rainy) and rabi (post-rainy) seasons mainly as a rain-fed crop (92% of the area) with about 85% of the production concentrated in Maharashtra, Karnataka and Andhra Pradesh, all falling under warm semi-arid region.

Sorghum [*Sorghum bicolor* (L.) Moench] rank fifth among the world's most important crops. More than 70% of the world's total production of sorghum comes from the developing countries in Asia and Africa, where crop is grown with limited water and nutrients.

It is one of the most nutritious cereals and is an important dry-land crop grown in poor and marginal lands with minimum inputs. It grows in dry conditions, tolerate to heat, salt and water-logging, making it an ideal crop for semi-arid areas where many of the world's poor live. It is now recognized worldwide as a smart crop capable of providing food, feed, fodder and fuel ("FFFF") especially under moderate inputs, especially in water deficit environments. It is also base crop on which many inter and sequence-cropping system is built upon. It is now realized that sorghum is of prime importance for the sustainable livelihood of the rural poor farmers who cannot afford purchased inputs. Further, the urban poor consumers having limited purchasing power will have benefit of nutritive millets grains since they are also made available as rice and wheat as low cost. Increasing industrial utilization, greater use as quality fodder and as adjunct in food and feed mixes can dramatically alter the demand of sorghum. Decline in per capita consumption was due to shift in consumer habits brought about by a number of factors such as faster urbanisation, time and energy required for sorghum based product like roti, inadequate domestic storage, poor marketing facilities, processing techniques and lower availability of grains.

One of the needs to cope with the changing climate scenario of rising temperature (hence increasing evaporation) is to improve the heat and drought tolerance of major food crops like wheat, rice and maize. The progress in these areas is generally low due to the complex nature of traits associated with these stresses. Sorghum and/or millets is a group of crops which have already inherited higher tolerance to heat, drought, salinity etc. Therefore, these crops have a better chance to get adapted to these supra-optimal conditions. Growing crops that are drought and heat tolerant is one form of adapting to the impacts of climate change. The ability of sorghum to grow in dry conditions, tolerate heat, salt and water-logging, makes it an ideal crop for semi-arid areas where many of the world's poor live. Carbon dioxide (CO_2) enrichment (also a consequence of global climate change) by 200 ppm has increased the water use efficiency of field grown sorghum by 9 and 19% under well watered, and water stressed conditions making it an ideal crop to choose under climate change. No doubt there is still need to improve genetic potential of sorghum for higher tolerance to these abiotic stresses. The other major challenge facing sorghum research and development workers is to provide technologies that will enable the agriculture sector to affect transformation of "subsistence farming" to a sustainable "market-oriented' enterprise successfully competing with the rest of world.

Sorghum can play a vital role in mitigating the impact of global warming by regulating the emission of greenhouse gases like nitrous oxide (N_2O), CO_2 and methane. There are two ways we can use sorghum profitably to control emission of harmful N_2O. First, there is world-wide criticism of our large cattle population being responsible for emitting gases because of poor digestibility of fodder. However, if we can increase the digestibly of fodder, same can be minimized. In sorghum, the brown mid-rib varieties (bmr mutants) have lower lignin, and higher digestibility. Cultivating such species coupled with better fodder management such as making silage or feed blocks will be useful to contain above criticism.

Secondly, nitrification releases fertilizer-N to the environment that contributes significantly to global warming, and serious nitrate pollution of surface and ground water bodies. As much as 50 to 70% of the fertilizer-N can be lost because of nitrification-associated processes. The annual economic losses to agricultural systems are estimated at US$ 16.4 billion. Therefore, regulation of nitrification could be the key strategy in improving nitrogen recovery and use efficiency particularly in dry land crops like sorghum. Recently, Japanese scientists have confirmed that some tropical grass species and millets like sorghum facilitate this. Thus, sorghum has a unique inbuilt ability of biological nitrification inhibition (BNI) in its root exudates through which it suppresses nitrification in soil. This indicates that sorghum can play a vital role in mitigating the impact of global warming by regulating the emission of N_2O to atmosphere, and enhance the nitrogen use efficiency, thereby retarding emission of undesirable gases.

Morphology of Sorghum: Sorghum, locally known as *jowar* is an annual plant that belongs to family *Gramineae* and genus *Sorghum*. Height of the plant varies from 0.5 to over 4 metres. The botanical description of main parts of sorghum plant is given below:-

Root System: Sorghum plant has a well developed root system. Roots are generally Liner and more fibrous than maize. The only temporary root in sorghum is the single radicles of the germinating seeding the rest of the roots are permanent in nature. The coronal roots develop from lowest nodes of the stem and are heavily branched. Most of the roots are confined to the upper 15 centimetre of soil, but in later stages of development, they may reach a depth of one or one and a half metre. Roots of sorghum are highly efficient to exhaust most of the nutrients and moisture available in the soil. Prop roots may develop from the axillary buds on the lowest nodes of the stem above the ground level. These roots are strong, and light green in colour. The main function of prop roots is to give support to the stem.

Stem: Sorghum stems are solid, through the centre may becomes spongy, with spaces in the pith. The thickness of the stem at base varies from 1-5 centimetres in diameter. The number of nodes differs with varieties but in general the culms are made up of 7-18 nodes and internodes. Generally sorghum does not produce tillers but occasionally from the lowest nodes the buds may give rise to tillers. It happens when plants fall down and node touches the ground. Stem of sorghum may be quite juicy and sweet or pithy and with very little juice. Central introduced fodder varieties are more juicy and sweeter than common grain varieties.

Leaves: The number of leaves on the main stem varies from 7 to 24 according to variety. Like the leaves of other cereals, a sorghum leaf possesses parallel veins and a mid-rib that the generally white in colour in dry and pithy varieties and dull green in juicy type of varieties. Mature leaves may reach a length of 30 to 135 centimetres, and a width of between 1.5 and 13 centimetres at the widest point. The stomata occur on both surface of the leaf and there are also lines of motor cells which cause the leaves to roll inwards under drought conditions. The arrangement of leaves on the stem is usually alternate in two ranks on opposite sides of stem. The leaf sheath encircles the stem and has overlapping margins. The length of the leaf sheath may vary between 15 and 35 centimetre. The sheath is smooth with a powdery bloom of wax on the upper side, and when tile deposit is heavy the sheaths have a blush-white appearance.

Inflorescence: The inflorescence of sorghum is a panicle. The panicles are commonly known as 'heads' and varies a great deal in size ranging from 7.5-50 centimetres in length and 4 to 20 centimetres in width. They may be compact or loose. The peduncle (the uppermost internode which bears the inflorescence) commonly known as the 'neck' may be straight or curved downwards (goose-necked). The panicle is composed of numerous spikelet, which usually occur in pairs, one of them being sessile and the other pedicellate. The sessile spikelet has two glumes. The glumes enclose two florets, the upper being perfect, the lower sterile and consisting of lemma only. There are two lodicules lying adjacent to the base of the spikelet. There are three stamens and a single-celled ovary with two long styles ending in stigmas. Generally one grain is formed as the result of fertilisation of the perfect floret. There are certain sorghum varieties which produce twin seeds in each spikelet, due to the second floret also being fertile. The pedicelled spikelet generally does not have functional ovary and hence does not produce seed. Many of the pedicellate spikelets fall off soon after the fertile sessile spikelet mature. In varieties where seed is produced in pedicelled spikelet, is always much smaller than those of the sessile spikelet. Sorghum is generally a self fertilised crop. Sorghum flowers being to open are those which are near the apex of the panicle and then blooming proceeds downwards in a fairly regular manner. Normally the flowers are pollinated from the higher flowers of the same panicle but natural crossing may also occur to some extent. Sorghum flower opens rapidly, owing to the pressure applied by the swelling of the two lodicules. The entire process may be completed in about 20-30 minutes.

Caryopsis (Grain): The grains are round, pointed at the base and have a slight depression near this end. Seed coat may be thin or thick. Colour of the grain may be white, pink, yellow brownish-yellow. Some white seeded varieties also have red, purple or brown spots on the grains. The caryopsis consists of endosperm, pericarp, testa and germ. Endosperm may be soft and floury or hard and corneous. Protein content may vary from 9 to 11 per cent. It is poor n lysine content (1.4 to 2.8%) while very rich in leucine (7.4 to 17%).

Species of crop: For many years most of the cultivated sorghums were classified into a single species, *Sorghum vulgare* Pers. However, this name is not the correct binomial designation (Doggett, 1965). The proper binomial terminology for al these sorghum is *Sorghum bicolor* (Linn) Moench. Since 1936, most sorghum workers used the classification of J. D. Snowden or some modification of it. The Snowden classification is very difficult to use, when one is dealing in thousand of accessions. Recently, Harlan and de Wet (1971) have developed a simple classification. According to Harlan and de Wet, the groups have been characterised by new scheme. The system partitions the variation in *Sorghum bicolor* (Linn) Moench into the following races:-

Basic Races: *Bicolor*, *guinea*, *caudatum*, *kafir*, and *durra*.

Hybrid Races: 1. *guinea– bicolor*, 2. *caudatum–bicolor*, 3. *kafir – bicolor*, 4. *durra–bicolor*, 5. *guinea–caudatum*, 6. *guinea–durra*, 8. *kafir–caudatum*, 9. *durra–caudatum*, 10. *kafir –durra*.

The above 15 races of cultivated sorghum can be identified, by mature spikelets alone although head type is sometimes helpful. The classification is based on five fundamental spikelet types – *bicolor*, *guinea*, *caudatum*, *kafir* and *durra* (Rao and House, 1972).

Nutritional value: Sorghum food consumption has many potential health benefits such as high anti-oxidant levels, improved cholesterol profiles of the consumer, and as a source of safe food for persons with celiac disease. Sorghum grain have high fibre content, moderate digestibility, rich mineral content compared to other cereals such as rice and wheat. Therefore, sorghum foods are recommended for diabetic and jaundice-affected persons and for fighting obesity. High tannin sorghum reduces risk of certain types of cancer when compared to other cereals. Sorghum wax has sterols like policosanols which regulates cholesterol absorption and endogenous cholesterol synthesis. The proximate composition of sorghum grain is given in **Table-5**.

Table-5: The proximate composition of sorghum grain (per 100 g)

Ingredient	Quantity	Ingredient	Quantity
Protein (g)	10.4	Lysine(g)	2.0
Carbohydrates(g)	72.6	Methionine(g)	1.4
Fat(g)	1.9	Cystine(g)	1.4
Crude fibre(g)	1.6	Phenylealanine(g)	4.9
Mineral matter(g)	1.6	Tyrosine(g)	2.7
Calcium(,g)	25	Threonine(g)	3.1
Phosphorus (mg)	222	Tryptophane(g)	1.1
Isoleucine(g)	3.9	Valine(g)	5.0
Leucine(g)	13.3	Hstidine(g)	2.1

Source: National Institute of Nutrition (N IN), Hyderabad.

Crop distribution (Area, Production & Yield): State-wise normal Area, Production and Yield of Sorghum is given at **Table-6**.

Table-6: State-wise Normal Area, Production and Yield of Sorghum (Average of 2007-08 to 2011-12)

States	Season	Area ('000' ha)	Production ('000' tonnes	Yield (Kg/ha)
Andhra Pradesh	Kharif	132.6	164.8	1243
	Rabi	172.4	253.8	1472
	Total	305.0	418.6	1373
Gujarat	Kharif	92.0	111.0	1207
	Rabi	50.8	51.8	1020
	Total	142.8	162.8	1140
Haryana	Kharif	75.2	37.0	492
Karnataka	Kharif	240.6	346.4	1440
	Rabi/Summer	1063.0	1151.0	1083
	Total	1303.6	1497.4	1149
Madhya Pradesh	Kharif	454.5	589.3	1297
	Rabi	2.5	3.3	1325
	Total	457.0	592.6	1297
Maharashtra	Kharif	1022.0	1364.2	1335
	Rabi	2924.8	2095.9	717
	Total	3946.8	3460.1	877
Rajasthan	Kharif	640.2	350.2	547
Tamil Nadu	Kharif	180.8	154.5	855
	Rabi	63.6	82.1	1291
	Total	244.4	236.6	968
Uttar Pradesh	Kharif	197.7	191.4	968
Others	Kharif	29.0	23.7	815
All India	**Kharif**	**3064.7**	**3332.4**	**1087**
	Rabi	**4277.1**	**3638.0**	**851**
	Total	**7341.8**	**6970.4**	**949**

1.2 Comparative analysis

The state and season specific distribution of grain sorghum in the country is given in **Table-7.**

Table-7: State/season specific distribution of sorghum in India (2007-08 to 2011-12)

State	Area (Lakh ha)			Production (Lakh tonnes)			Yield (kg/ha)		
	Kharif	Rabi	Total	Kharif	Rabi	Total	Kharif	Rabi	Total
Maharashtra	10.22 (33.3)	29.25 (68.4)	39.47 (53.8)	13.64 (40.9)	20.96 (57.6)	34.60 (49.6)	1335	717	877
Karnataka	2.41 (7.9)	10.63 (24.9)	13.04 (17.8)	3.46 (10.4)	11.51 (31.6)	14.97 (21.5)	1440	1083	1149
Rajasthan	6.40 (20.9)	-	6.40 (8.7)	3.50 (10.5)	-	3.50 (5.0)	547	-	547
Madhya Pradesh	4.55 (14.9)	0.02 (Neg.)	4.57 (6.2)	5.89 (17.7)	0.03 (0.1)	5.92 (8.5)	1297	1325	1297
Andhra Pradesh	1.33 (4.3)	1.72 (4.0)	3.05 (4.2)	1.65 (5.0)	2.54 (7.0)	4.19 (6.0)	1243	1472	1373
Tamil Nadu	1.80 (5.9)	0.64 (1.5)	2.44 (3.3)	1.55 (4.7)	0.82 (2.3)	2.37 (3.4)	855	1291	968
Uttar Pradesh	1.98 (6.5)	-	1.98 (2.7)	1.91 (5.7)	-	1.91 (2.8)	968	-	968
Gujarat	0.92 (3.0)	0.51 (1.2)	1.43 (1.9)	1.11 (3.3)	0.52 (1.4)	1.63 (2.4)	1207	1020	1140
Haryana	0.75 (2.4)	-	0.75 (1.0)	0.37 (1.1)	-	0.37 (0.5)	492	-	492
Others	0.29 (0.9)	-	0.29 (0.4)	0.24 (0.7)	-	0.24 (0.3)	815		815
All India	**30.65 (100)**	**42.77 (100)**	**73.42 (100)**	**33.32 (100)**	**36.38 (100)**	**69.70 (100)**	**1087**	**851**	**949**

NB: Figures in parenthesis indicate % share to All India.

Grain sorghum is grown everywhere in Semi-arid tropics of India. It is grown during Kharif (Rainy), Rabi (Post-rainy) and to a lesser extent during summer season also in these areas. Whereas, dual purpose and forage sorghum are grown across the States predominantly during Kharif season particularly in North-Western Plans and Central India. Maharashtra State alone cultivates 53.8% of total sorghum area with 49.6% of total production followed by Karnataka (17.8%), Rajasthan (8.7%), Madhya Pradesh (6.2%), Andhra Pradesh (4.2%), Tamilnadu (3.3%) & Uttar Pradesh (2.7%). The sorghum area under irrigation was 8.7% during 2009-10.

The productivity of Kharif sorghum is comparatively higher than Rabi. The highest productivity is recorded in Karnataka State during Kharif season but grain quality often gets deteriorated due to October-November rains.

The productivity of Rabi sorghum is low as the crop is grown on conserved soil moisture/marginal lands with almost no irrigation.

Area, Production & Yield of major crop growing countries: Mean area, production and yield (2007-2011) of sorghum is given at **Table-8**.

Table-8: Mean area, production and yield of sorghum (2007-2011)

Sl.No.	Country	Area (million ha)	Production (Million tonnes)	Yield (Kg/ha)
1	**Argentina**	**0.7 (1.7)**	**3.1 (5.2)**	**4556**
2	Australia	0.7 (1.7)	2.3 (3.9)	3255
3	Benin	0.1 (0.2)	0.2 (0.3)	1141
4	Bolivia (Plurinational State of)	0.1 (0.2)	0.4 (0.7)	3450
5	Botswana	0.1 (0.2)	0.0 (Neg.)	595
6	Brazil	0.7 (1.7)	1.8 (3.0)	2364
7	Burkina Faso	1.8 (4.3)	1.7 (2.9)	951
8	Burundi	0.1 (0.2)	0.1 (0.2)	1289
9	Cameroon	0.7 (1.7)	1.0 (1.7)	1454
10	Chad	0.9 (2.2)	0.6 (1.0)	745
11	China	0.5 (1.2)	1.8 (3.0)	3551
13	**Egypt**	**0.1 (0.2)**	**0.8 (1.3)**	**5441**
14	El Salvador	0.1 (0.2)	0.1 (0.2)	1475
15	Eritrea	0.3 (0.7)	0.1 (0.2)	445
16	Ethiopia	1.7 (4.1)	2.8 (4.7)	1697
17	Ghana	0.2 (0.5)	0.3 (0.5)	1161
18	Haiti	0.1 (0.2)	0.1 (0.2)	845
19	Honduras	0.1 (0.2)	0.1 (0.2)	1021
20	**India**	**7.8 (18.8)**	**7.2 (12.1)**	**925**
21	Kenya	0.2 (0.5)	0.1 (0.2)	684
22	Malawi	0.1 (0.2)	0.1 (0.2)	778
23	Mali	1.2 (2.9)	1.2 (2.0)	961
24	Mauritania	0.2 (0.5)	0.1 (0.2)	440
25	**Mexico**	**1.8 (4.3)**	**6.5 (10.9)**	**3669**
26	Mozambique	0.6 (1.4)	0.4 (0.7)	657
27	Myanmar	0.2 (0.5)	0.2 (0.3)	944
28	Niger	2.9 (7.0)	1.0 (1.7)	345
29	**Nigeria**	**6.0 (14.5)**	**7.5 (12.6)**	**1256**
30	Pakistan	0.2 (0.5)	0.2 (0.3)	621
31	Rwanda	0.1 (0.2)	0.2 (0.3)	1129
32	Saudi Arabia	0.1 (0.2)	0.3 (0.5)	2867
33	Senegal	0.2 (0.5)	0.2 (0.3)	865
34	Somalia	0.3 (0.7)	0.1 (0.2)	267
35	South Africa	0.1 (0.2)	0.2 (0.3)	2666
36	**Sudan (former)**	**5.1 (12.3)**	**3.1 (5.2)**	**618**
37	Togo	0.2 (0.5)	0.2 (0.3)	1053
38	Uganda	0.3 (0.7)	0.4 (0.7)	1260
39	Ukraine	0.1 (0.2)	0.1 (0.2)	2110
40	United Republic of Tanzania	0.7 (1.7)	0.8 (1.3)	1032
41	**United States of America**	**2.3 (5.6)**	**9.7 (16.3)**	**4239**
42	Venezuela (	0.2 (0.5)	0.4 (0.7)	1936
43	Yemen	0.5 (1.2)	0.5 (0.8)	911
44	Zimbabwe	0.3 (0.7)	0.1 (0.2)	279
	World total	**41.4**	**59.5**	**1438**

NB: Figures in parenthesis indicate % share to World total.

Sorghum is mostly grown in arid and semi-arid regions of the world over an area of 41.40 million ha, production of 59.5 million tonnes and productivity of 1438 kg/ha during 2007-11. India has the largest coverage 7.8 million ha (18.8%) in the world followed by Nigeria (6 million ha) Sudan (5.1 million ha), whereas, USA is the major sorghum producer (16.3%) followed by Nigeria (12.6%), India (12.1%) and Mexico (10.9%). The productivity of sorghum was highest in Egypt (5441 Kg/ha) followed by Argentina (4556 Kg/ha) and USA (4239 Kg/ha) during 2007-11, whereas, productivity in India was 925 Kg/ha.

1.3 Varietal development

Organised sorghum research, its national co-ordination and network technology evaluation were initiated on a modest scale during the late 1960's. The All India Co-ordinated Sorghum Improvement Project (AICSIP) network with 18 main centres spread over thirteen State Agriculture Universities in ten major sorghum growing states, played the key role on evaluation and identification of superior cultivars and production technologies. Sorghum is one of the earliest crops where in cytoplasmic male sterility system was deployed to fix yield heterosis. First commercial sorghum hybrid, CSH-1, was released in 1964 using the parental lines bred in USA and supplied by the Rockefeller Foundation. Indian sorghum breeding since then steadily gained competence and moved to the vanguard. It generated a completely new genetic variability based on zera zera, feterita and durra germplasm developed superior parental lines and produced high yielding hybrids possessing nationally preferred grain and agronomic attributes. While sorghum research was being carried out during pre-independence years, concerted research efforts on productivity enhancement and a national effort to popularise technologies promoting high productivity was initiated in 1962 with the establishment and Accelerated Sorghum and Millet Improvement Project (ASMIP). ASMIP was the fore-runner of the All India Co-ordinated Sorghum Improvement Project (AICSIP) which was established in 1969. A modest genetic enhancement programme undertaken under AICSIP with a total. A substantial improvement in the productivity of Kharif sorghum through high yielding hybrids and in the production technologies to enabled the harvest of better yield.

Thereafter, a large number of hybrids, varieties/composites of sorghum have been developed. Development/release of 21 hybrids and 41 varieties/composites during last 15 year (1995-2010) shows a larger genetic variability and yield potential in sorghum. The varieties/hybrids are as under:-

Hybrids: CSH-13, CSH-16, CSH-17, CSH-18, CSH-21, CSH-22 SS, CSH-23, CSH-12 R, CSH-13 R, CSH-15 R, CSH-19 R, MLSH-296, SPH-837, SPH-840, SPH-1567, PSH-1, DSH-4 R, ASH-1, ICI-501, JKSH-22, Mahabeej-7. CSH-25, CSH-27 & CSH-30 are the latest hybrids released.

Varieties: SPV-462, SPV-1626, SPV-1333 (Parbhani Sweta), SPV-1388 (Bundela), SPV-1411 (Prabhani Moti), SPV-1430 (Pratap Jowar) SPV-1546 (Phule Chitra), SPV-1626, SPV-1704 (Vasudha), SSV-84, CSV-15, CSV-17, CSV-18, CSV-19 SS, CSV-20, CSV-23, CSV-216, Nandyal Tela Jona-3, ICSV-239 (BSR-1), ICSV-745, Palem-2, Kinnerea, DSV-4, DSV-5, DSV-6, JJ-938, JJ-1041, GJ-38, GJ-39, GJ-40, GJ-41, RSSV-9, RSLG-262 (Maulee), RSSGV-3 (Uttara), AKSV-13, AKSSV-22, Pratap Jowar-1430, Paiyur-2, CO (S)-28, K-11 and APK-1. CSV-22, CSV-24 SS and CSV-27 are the latest varieties.

These hybrids and varieties have played a significant role in productivity improvement from 440 Kg/ha (1961-62) to 962 Kg/ha (2011-12), despite the fact that sorghum is largely (> 90 %) grown under rainfed farming. The State-wise status of recommendation/release of new varieties/hybrids during 1995-2010 and the varieties/hybrid popular in the States is given below in **Table-9**.

Table-9: State wise status of popular Hybrids/Varieties of sorghum

State	Season/ uses	Hybrids/varieties released/ recommended during last 15 years.	Hybrids/varieties popular in the State
Andhra Pradesh	*Kharif*	**Hybrids:** CSH-13, MLSH-296, CSH-16, JKSH-22, PSH-1, CSH-18, ASH-1, CSH-21, & CSH-23.**Varieties:** SPV-462, CSV-15, Nandyal Tella Jona-3, Palem-2, CSV-23, CSV-17, CSV-18, CSV-20 & Kinnerea.	**Hybrids:** CSH-5, CSH-6, CSH-9, CSH-**16**; **ASH-1**, ICMH-451 & ICTP-8203. **Varieties:** PSV-1, CSV-14 R, PJ-890, SJ-092, 122, 2169, **Palem-2**, N-13, N-14, APS-1, ICMV-221 & **SPV-462.**
	Rabi	**Hybrids:** CSH-12 R, CSH-13 R, CSH-15 R & CSH-19 R. **Varieties:** CSV-216 & SPV-1626.	
	Sweet sorghum	CSH-22 SS.	
	Fodder	**Hybrid**s: Hara Sona & Pantchari-5.	
Bihar	*Kharif*	**Hybrid**- CSH-16 **Variety**- CSV-15	**Hybrids:** CSH-1, CSH-2, CSH-3, CSH-5, Swarna hybrid-, BR-1 & BR-2.
	Fodder	CSH-20-MF	MP Chari & Pusa Chari-1
Gujarat	*Kharif*	**Hybrids:**– CSH-13, CSH-16, CSH-17, JKSH-22, CSH-18, CSH-21, & CSH-23 **Varieties:** GJ-38, GJ-39, CSV-15, GJ-40, GJ-41, RSV-9 (CSV-19 SS), CSV-23, CSV-17 & CSV-20.	**Hybrids:** GJ-37, GJ-39, GJ-40 & GJ-41.
	Rabi	**Hybrids:** CSH-13 R & CSH-19 R. **Variety:** SPV-1626.	
	Sweet sorghum	CSH-22 SS.	
	Fodder	**Hybrid** – Hara Sona, Pusa Chari Hybrid-106, Pant Chari-5, CSH-20-MF, Gujarat Fodder Sorghum-5 & CSH-24.	JF-4, CSH-5 & CSH-6.
Haryana	*Kharif*	**Hybrid:** CSH-16 **Varieties:** CSV-15, SSV-84 & CSV-23.	Not indicated by the State.
	Fodder	**Hybrid** – Hara Sona, Haryana Chari-308, Pusa Chari Hybrid-106, Pantchari-5, CSH-20-MF, Haryana Jowar-513 & CSH-24.	Not indicated by the State.
Karnataka	*Kharif*	**Hybrids:** CSH-13, MLSH-296, CSH-216, CSH-21, & CSH-23. **Varieties:** – CSV-15, ICSV-745, SPV-462, RSSV-9, CSV-17, CSV-18, and CSV-20 & DSV-6.	Not indicated by the State.
	Rabi	**Hybrids:** CSH-15 R, CSH-19-R & DSH-4 R. **Varieties:** DSV-5, DSV-4, CSV-216 & SPV-1626.	
	Sweet sorghum	CSH-22 SS	
	Fodder	Hara Sona	

Table-9 contd….

State	Season/ uses	Hybrids/varieties released/ recommended during last 15 years.	Hybrids/varieties popular in the State
Madhya Pradesh	*Kharif*	**Hybrids:** CSH-13, CSH-16, ICI-501, CSH-17, CSH-18, CSH-21, CSH-22 SS, CSH-23. **Varieties:** CSV-15, Jawahar Jowar-938, Jawahar Jowar-1041, CSV-17 & CSV-20.	**Hybrids:** CSH-5, CSH-16, CSH-9 & CSH-14. **Varieties:** JK-22, JK-741, JK-938, JK-1041, SPV-15, CSV-15 & SPV-1022.
	Fodder	Hara Sona & Pantchari-5	-
Maharashtra	*Kharif*	**Hybrids:** CSH-13, CSH-16, MLSH-296, ICI-501, CSH-18, Mahabeej-7, SPH-840, CSH-21, CSH-23, CSH-21, CSH-23 & SPH-1567. **Varieties:** CSV-15, Parbhani Sweta, PVK-809, CSV-17, CSV-18 & CSV-20.	**Hybrids:** CSH-9 & CSH-14.
	Rabi	**Hybrids:** CSH-15 R & CSH-19 R. **Varieties:** CSV-216 (Phule Yashoda), RSLG-262 (Maulee), Parbhani Moti, Uttara, SPV-1626, Vasudha, AKSV-13 R & Phule Chitra.	**Varieties:** M-35, Prabhani Moti, Prabhani Sweta, Phule Yashoda, Phule Maulee.
	Fodder	**Hybrid** – Hara sona, Pusa chari hybrid-106 & Pusa chari-5.	–
	Sweet sorghum	**Hybrid** – CSH-22 SS, Variety – Phule Amrita & AKSSV-22.	–
Rajasthan	Kharif	**Hybrids:** CSH-13, CSH-16, CSH-17, CSH-18, MLSH-296, ICI-501, SPH-837 & CSH-23. **Varieties:** CSV-15, Partap jowar-1430, CSV-23 & CSV-17.	**Hybrids:** CSH-16, CSH-17, CSH-6, CSV-15, CSH-9, Partap Jowar-1430, SPH-837 & SPV-245.
	Sweet sorghum	CSH-22 SS	
	Fodder	Hara sona, Haryana chari-308, Pant chari-5 & CSH-20-MF.	
Tamilnadu	*Kharif*	**Hybrids:** CSH-13, MLSH-296, CSH-16, ICI-501 & CSH-17. **Varieties:** CSV-15, BSR-1, SPV-462, Paiyur-2, CO (S) 28, K-11, CSV-23 & CSV-17.	**Hybrids**: CSH-1, CSH-5, CSH-6, COH-3, COH-4,. **Varieties:** CO(S) -28, CO(S)-26, APK-1, Payur-1, Payur-2, CO-10, CO-18, CO-19, CO-21, CO-25, CO-26, K-4, K-5, K-6, K-7, K-8, K-9, K-10, K-11, K Tall, BSR-1, IS 3541.
	Rabi	**Hybrid:** CSH-19 R. **Varieties:** BSR – 1, APK – 1, Paiyur-2, CO(S)28, K-11 & SPV-1626.	
	Summer	CO(S) 28 & K-11.	
	Fodder	Hara sona, Pant chari-5 & CO (FS) 29.	
	Sweet sorghum	CSH-22 SS.	
Uttar Pradesh	*Kharif*	**Hybrids:** CSH-13, CSH- 16, CSH-18, CSH-23. **Varieties:** CSV-15, Bundela, CSV-23, CSV-17 & CSV-20.	–
	Fodder	Hara sona, Haryana chari-308, Pant chari-4, Pant chari-5 & Pusa chari-106.	
	Sweet sorghum	CSH-22 SS.	

The above statement indicates that adoption of new varieties/hybrids is slow mainly because of less focus on seed production. The task of promotion of new varieties/hybrids particularly the varieties/hybrids released at National Level could be entrusted to National Level seed producing agencies like NSC and SFCI.

Reasons for non-adoption of new hybrid/variety by the states and farmers:

- Non-availability of seeds of high yielding cultivars in the market at proper time, place and price.
- Biotic stresses such as shoot fly at early stage and grain mould disease.
- Severe birds' damage due to sporadic cultivation of this crop
- Competition with cash crops like cotton, soybean, oilseeds, vegetables, etc.
- Inadequate policy support to promote sorghum grain through public distribution system (PDS) and mid-day meal scheme.
- Fast changing food habits of human being and unawareness of nutritional value of sorghum for health.

Yield potential and gap in sorghum: There are hybrids with yield potential of > 5 tonne per ha (PSH-1) and also open pollinated varieties with yield potential of > 4 tonnes per ha (NTJ-3). **FLDs** have been organized by the Directorate of Sorghum Research, Hyderabad over an area of 1997 ha during Kharif (1099 ha) and *Rabi* (878 ha) during 2000-01 to 2009-10 through its centres located in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamilnadu and Uttar Pradesh on improved production technology of grain sorghum. Besides, FLDs were also conducted over an area of 307 ha on forage production. The state wise progress of FLDs of grain sorghum is given below in **Table-10**.

Yield potential and gap in sorghum: FLDs have been organized by the Directorate of Sorghum Research, Hyderabad over an area of 817.15 ha during 2008-09 to 2012-13 through its centres located in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamilnadu on improved production technology of grain sorghum. The state wise progress of FLDs of grain sorghum during 2008-09 to 2012-13 is given below in **Table-10**.

Table-10: The state wise progress of FLDs of grain sorghum

Sl. No.	State	Season	Year wise area (ha) under FLD					
			08-09	09-10	10-11	11-12	12-13	Total
1	Andhra Pradesh	*Kharif*	-	2.00	10.90	-	-	12.90
		Rabi	-	20.00	23.20	50.00	70.40	163.60
		Total	-	22.00	34.10	50.00	70.40	176.50
2	Gujarat	*Kharif*	-	14.00	14.30	-	-	28.30
		Rabi	-	-	-	-	-	-
		Total	-	14.00	14.30	-	-	28.30
3	Karnataka	*Kharif*	-	-	-	-	-	-
		Rabi	-	26.00	88.00	-	20.00	134.00
		Total	-	26.00	88.00	-	20.00	134.00
4	MP	Kharif	-	27.00	11.20	-	-	38.20
5	Maharashtra	*Kharif*	-	35.00	10.40	-	-	45.40
		Rabi	-	123.00	139.40	-	64.00	326.40
		Total	-	158.00	149.80	-	64.00	371.80
6	Rajasthan	*Kharif*	-	21.00	21.35	-	-	42.35
7	Tamilnadu	*Kharif*	-	16.00	10.00	-	-	26.00
		Rabi	-	-	-	-	-	-
		Total	-	16.00	10.00	-	-	26.00
Year wise total area			**-**	**284.00**	**328.75**	**50.00**	**154.40**	**817.15**

Table-11: Yield performance of FLDs of sorghum during *Kharif* season

Sl.No.	State	Plot	Year wise yield in Kg/ha					
			08-09*	09-10	10-11	11-12*	12-13*	Mean
1	Andhra Pradesh	FLD	-	3500	2930	-	-	3215
		Control	-	2450	2100	-	-	2275
		SAY	-	995	1000	-	-	998
		% Yield gap over					**Control**	**41**
							SAY	**222**
2	Gujarat	FLD	-	2160	3010	-	-	2585
		Control	-	1630	2250	-	-	1940
		SAY	-	1063	1066	-	-	1065
		% Yield gap over					**Control**	**33**
							SAY	**143**
3	Madhya Pradesh	FLD	-	2330	2250	-	-	2290
		Control	-	1860	1780	-	-	1820
		SAY	-	1267	1426	-	-	1347
		% Yield gap over					**Control**	**26**
							SAY	**70**
4	Maharashtra	FLD	-	2360	2320	-	-	2340
		Control	-	2100	2030	-	-	2065
		SAY	-	1083	1325	-	-	1204
		% Yield gap over					**Control**	**13**
							SAY	**94**
5	Rajasthan	FLD	-	1640	1980	-	-	1810
		Control	-	350	1040	-	-	695
		SAY	-	145	700	-	-	423
		% Yield gap over					**Control**	**60**
							SAY	**328**
6	Tamilnadu	FLD	-	1220	1200	-	-	1210
		Control	-	730	680	-	-	705
		SAY	-	855	803	-	-	829
		% Yield gap over					**Control**	**72**
							SAY	**46**

* FLD programme could not be implemented.

The above statement reveals largest yield gap over State Average Yield (SAY) in Rajasthan (328%) followed by Andhra Pradesh (222%), Gujarat (143%), Maharashtra (94%), Madhya Pradesh (70%) with least gap in Tamil Nadu (46%). Tamil Nadu has largest yield gap (72%) over farmer practice average yield followed by Rajasthan (60%), Andhra Pradesh (41%), Gujarat (33%), Madhya Pradesh (26%) with minimum yield gap in Maharashtra (13%). The largest yield gap in Rajasthan may be because of poor soil fertility and wide rainfall fluctuations. However, overall wider yield gaps shows a significant scope for yield improvement of sorghum during *Kharif* season with the adoption of improved cultivars and technologies through a well planned strategy in identified areas. The application of protective irrigation at flag leaf and grain filling stage could boost the productivity of sorghum.

Table-12: Yield performance of FLDs of sorghum during *Rabi* season

Sl.No.	State	Plot	Year wise yield in Kg/ha					
			08-09*	09-10	10-11	11-12*	12-13	Mean
1	Andhra Pradesh	FLD	-	7550	2190	8620	1660	5005
		Control	-	7110	1730	6060	1090	3998
		SAY	-	1265	1386	1671	1467	1447
		% Yield gap over					**Control**	**25**
							SAY	**246**
2	Karnataka	FLD	-	1375	1270	-	1080	1242
		Control	-	1220	995	-	680	965
		SAY	-	1019	1093	-	1050	1054
		% Yield gap over					**Control**	**29**
							SAY	**18**
3	Maharashtra	FLD	-	1540	1137.5	-	1280	1319
		Control	-	980	755	-	730	822
		SAY	-	776	689	-	404	623
		% Yield gap over					**Control**	**60**
							SAY	**112**

* FLD programme could not be implemented.

The above statement reveals largest yield gap over State average yield in Andhra Pradesh (246%) followed by Maharashtra (112%) with least gap in Karnataka (18%), whereas, Maharashtra indicates largest yield gap (60%) over farmer practice average yield followed by Karnataka (29%) and Andhra Pradesh (25%). The larger gap may be because that the *Rabi* sorghum is grown on conserved moisture and productivity depends on intermittent rains received during the crop season. The technology of moisture conservation and use of rain water harvesting could help in productivity improvement of *Rabi* sorghum.

1.4 Climatic requirement

Temperature for different critical stages: Sorghum (*Sorghum bicolor* (L.) Moench) is the major nutritional coarse grain cereal crop grown for food, feed, and bioenergy in India and around the world. It is grown in India over 7.65 m ha both in kharif (3.00 m ha) and Rabi (4.65 m ha) seasons. Both biotic and aboitic (drought and temperature extremities (high followed by low temperatures) occurring during pre-and post flowering stages limits sorghum productivity. Average yields are d”1.0 t ha-1 due to negative impacts of abiotic and biotic stresses. Further, climate change especially short episodes of high temperature (above optimum) are projected to impact the sorghum yields considerably (Prasad et al. 2008).

Temperature variability in sorghum growing Areas in India: The temperature variation between different sorghum growing areas varies widely. Based on 30-year normal's (IMD 1967), the rainy season average temperatures vary from 31°C in June to 23°C in November. In the post-rainy season, average temperature varies from 22°C to 29°C. The maximum temperature variation during the rainy season is not significant, but the minimum temperatures decrease from 25°C to about 20°C by physiological maturity. In the post-rainy season, however, the maximum temperature increases from 30°C at the end of October to 35°C by March. In terms of sorghum crop phenology, the diurnal range in temperature is rather small in the rainy season and the uniformly high temperatures should promote good vegetative growth and grain- filling. In the post-rainy season, the diurnal range in temperature, especially around flowering, is rather large and the minimum temperatures are consistently low (>15.0°C). Peacock (1982) suggests that the extreme temperatures are as relevant to sorghum growth as the average temperature. The highest and lowest air temperatures recorded in the rainy sorghum-growing season at selected locations are presented in Table below. Maximum temperatures could reach as high as 45°C, as at Jhansi, while the temperature dip could extend to as low as 8°C in November at Indore. In rabi season, highest temperatures of up to 38-40°C could be recorded, while minimum temperatures of 8-10°C are not uncommon.

Highest and lowest air temperatures (⁰C) recorded at selected locations in *kharif* season.

Location		June	July	Aug	Sept	Oct	Nov
Akola	Maximum Minimum	42.2 22.5	36.2 21.8	31.4 21.7	35.0 21.1	35.6 14.7	33.6 10.6
Hyderabad	Maximum Minimum	39.9 21.2	34.0 21.0	33.0 20.9	32.8 20.3	33.3 15.8	31.5 11.8
Indore	Maximum Minimum	40.1 21.4	34.1 21.0	31.5 20.4	32.6 18.9	33.2 13.0	31.2 8.2
Jhansi	Maximum Minimum	44.9 23.8	39.6 23.1	35.5 22.7	35.6 21.6	36.0 14.7	33.4 8.8

Source: Sivakumar and Virmani (1982)

Highest and lowest air temperatures (⁰C) recorded at selected locations in Rabi season

Location		Oct	Nov	Dec	Jan	Feb
Bijapur	Maximum Minimum	33.6 17.0	31.8 12.9	31.4 11.1	32.7 12.0	35.8 14.1
Gulbarga	Maximum Minimum	34.4 16.8	32.8 12.9	31.5 10.5	32.7 11.7	36.1 14.6
Solapur	Maximum Minimum	34.7 16.6	32.2 12.9	31.9 10.7	33.3 11.3	36.4 13.1
Ahmadnagar	Maximum Minimum	33.5 14.5	32.2 10.5	31.1 8.0	32.0 8.0	34.4 9.6

Source: Sivakumar and Virmani (1982)

Cardinal temperatures for Sorghum growth and development*:* Temperature is the major driving force for the rate of development. Sorghum is a warm season species which requires relatively high temperature for growth. At certain minimum temperature plant growth begins and at certain maximum temperature growth ceases. Somewhat between an optimum range of temperature growth is active. The temperature requirement for various growth and developmental processes are presented in table on the next page. In postrainy reason there was interaction between photoperiod and temperature.

Cardinal temperature for Sorghum growth and development

Stage	Temperature	Reference
Optimum for growth	30^0C to 35^0C	(Eastin, 1983); Ritchie and Alagarsamy, (1989)
Optimum for photosynthesis	40^0C	(Eastin, 1983)
Minimum for germination	7 - 10^0C	Quinby et al (1958)
Seedling emergence Maximum (Lethal)	15-20^0C 45-48^0C	Singh and Dhaliwal (1972) Kailasanathan et al. (1976)

Temperature effects on sorghum phenology: High temperature promote vegetative growth rather than at reproductive stage. High day/ night temperatures (35/30^0C) usually increase the leaf number in sorghum than at low temperatures (25/20^0C). Both photoperiod and temperature interaction will determine the number of leaves to be produced. Furthermore, temperatures <15^0C and >35^0C generally reduce the pollen viability and seed set (Rao et al 2004). Understanding the impacts of climate change and climate variability requires improved understanding of the impacts of increased mean temperatures as well as the impacts of short-term extreme temperatures (Wheeler et al., 2000).

Thermal time (Growing degree days (GDD): It is the reliable estimate of crop development than calendar days. The GDD for different growth stages i.e. from 0 to 9 stages can be calculated as follows: GDD =daily max.air temp + daily min.air temp/2-Base temp. The mean and cumulative GDD recorded for each growth stage during kharif and rabi seasons are presented in Table below:-

Mean and cumulative GDD for different growth stages in sorghum.

Growth stage no.	Growth stage name	Mean GDD for each stage (degree days)		Cumulative GDD (degree days)	
		Kharif 2003	Rabi 2003/04	Kharif 2003	Rabi 2003/04
0	Emergence	108	89	206	181
1	3 Leaf	114	155	320	336
2	5 Leaf	197	154	516	490
3	Panicle initiation	269	293	785	783
4	Flag leaf visible	424	153	1209	936
5	Boot	140	177	1349	1134
6	50% flowering	155	151	1504	1265
7	Soft dough	211	198	1715	1463
8	Hard dough	288	234	2002	1696
9	Physiological maturity	165	137	2167	1833

Source: Rao et al (2014)

High temperature effects on sorghum: In general, temperature determines the rate of plant growth and development. Most of these are well described by a linear relationship between temperature and rate of development from base temperature to optimum temperature, above which the rate of development can decrease again (Peacock and Heinrich.1984). In sorghum, heat stress (35–30°C) increases plant growth, leading to increased transpiration and decreased soil water content (Machado and Paulsen, 2001). Prasad et al., (2006) demonstrated the effect of season-long and short episodes of high temperatures stress on sorghum growth and yield. Both drought (water stress) and heat stress (above-optimum air temperatures) often occur together, and have significant effects on various physiological, growth, developmental, and yield processes. Very limited information is available on the extent of heat stress on tropical sorghum crop productivity. Combined effects of drought and heat had a significantly detrimental effect on sorghum growth and productivity when each stress was applied individually (Craufurd and Peacock, 1993).Both developmental rate of individual organs such as leaves and the progress of the entire plant through various ontogenetic stages are quantitatively dependent on temperatures (Sinclair, 1994). In general, warmer temperature stimulates more rapid development of leaf canopy and also causes the overall crop growth and development rate to increase so that the crop growing season is shortened. In general, the higher the temperature the faster is the development and thus the shorter is the duration of the growth phase.

Temperature effects on sorghum reproductive processes*:* Drought or heat stress during anthesis can lead to failure of fertilization because of decreasing pollen or ovule function. Drought stress or heat stress inhibits pollen development and causes sterility. Drought and/or heat stress also shortens the duration and differentiation of panicle development (GS2 stage: period during which potential kernel or seed numbers are determined) and also the rate of grain growth and grain-fill duration (GS3: during which the grain or seed weight is determined). In cereal crops such as sorghum, and millet, which produce large amounts of pollen grains, the ability of pollen to germinate or growth of pollen tube inside the style is more sensitive to high temperature stress. Loss of pollen viability under heat or drought stress would decrease seed-set if the amount of pollen was also limited and/or if anther dehiscence was influenced by stress. Both microsporogenesis (pollen development) and mega-sporogenesis (stigma development) are affected under heat stress, resulting in lower seed-set (Young et al., 2004). Pollen is known to be relatively more sensitive to heat stress. The mechanisms responsible for pollen sterility, lower seed-set or early embryo abortion under heat stress need further investigation.

Sensitive Stages to Heat Stress*:* The impacts of heat stress on sorghum growth and yield depend on the severity and duration of stress and the plant developmental stage at which the stress occurs. The most sensitive stages of development to drought stress are generally during panicle development, boot and during flowering (Prasad et al., 2006).

Photoperiod and temperature interactions in relation to sorghum adaptation*:* Crop plants can be divided into temperate, tropical, sub-tropical based on their adaptation to particular climate. Crop plants can be classified according to how they are influenced by relative lengths of day or night. Certain cultivars of crops will not reach reproductive development until the day length is 14 or more h these plants are called long day plants (LDP) eg. Wheat, Oats and Barley. On the other hand, crops, such as sorghum, corn, millet are short day plants and requiring day length of less than 14 hours to initiate reproductive cycle. SDPs are remaining vegetative when grown under conditions of long days. Most sorghums grown in tropical climates are relatively sensitive to photoperiod and tall to medium tall, while the temperate sorghum grown in higher latitudes such as USA photoperiod insensitive and short in height that are amenable to combine harvesting.

High temperature impact on grain yield*:* Heat and drought stress decreased the sorghum grain yields by 87% when stress imposed between boot and flowering stages (late stress) in the early flowering lines, while the same stress treatment on vegetative plants had no effect on grain yield (Crauford and Peacock, 1993). Elevated night temperatures (5°C above optimum) during differentiation and expansion of pistil and stamen primordia can reduce yield 25-35% because of seed number reduction (Eastin, 1983).

***Climatic resilience of sorghum**:* The earth's climate is predicted to change through the buildup of greenhouse gases -primarily carbon dioxide, methane, nitrous oxide and chlorofluorocarbons. The major impact of climate change due to this buildup of green house gases will be increase in atmosphere temperatures. Increased water shortages, rising sea levels (may result in more saline lands), reduced crop yields, more floods and increase in human and animal diseases are some of the serious problems being expected under climatic change scenario. Farmers can no longer rely on the rainy seasons as before. The rise in temperatures will left many boreholes dry and streams having no water. These impacts of climate change are due to the large amount of gases such as carbon dioxide and methane that are being pumped in the air by human activities and industries. It is said that in the near future, the ice on many mountains will disappear, and that many parts of the world will experience floods, droughts and forest fires, as a result of climate change. That means many people will have little food to eat and there will be no excess produce to sell in order to afford basic needs. Growing crops, that are drought and heat resistant, is one form of adapting to the impacts of climate change. Sorghum is one of the crops which have inherited its trait to adapt and grow in harsh climate from its origin. It grows in dry conditions, tolerates heat, salt and water-logging, making it an ideal crop for semi-arid areas where many of the world's poor live.

Possible alternate crops & varieties in the event of natural calamities like drought & floods

Natural calamities	**Possible alternate crops and varieties**
GUJARAT	
Initial drought: 1. Delay in monsoon by 15th July to 31st July	Groundnut (GG2, GG5, GG7); Sesame (G Till 1, G Till 2), Castor (GAUCH 1); Hybrid bajra (GHB 235, GHB 316, GHB 558); Greengram (K 851, GM 4),Blackgram (T9, TPU 4),Pigeonpea (ICPL 87, GT 100).
2. Delay in monsoon by 1st August to 14th August	Blackgram (T9, TPU 4), Forage maize/sorghum (Gundri, GFS-5), Castor (GAUCH 1, GC 2); Sesame (Purva 1)
3. Delay in monsoon by 15th August to 31st August	Forage maize/sorghum (Gundri, GFS-5), Sesame (Purva 1)
Drought spell after normal sowing	
1-2 weeks after sowing	Sesame (G Till 1, G Till 2), Castor (GAUCH 1, GC 2); Hybrid bajra (GHB 235, GHB 316, GHB 558); Sorghum (GJ 39, J-41), Black gram (T9, TPU 4).
3-5 weeks after sowing	Ratooning of sorghum
KARNATAKA	
If Normal rain occurs in 2nd fortnight (FN) of July	Groundnut, finger millet
1st FN August	Cowpea, horse gram, short duration finger millet, transplanting of chilli
2nd FN August	Short duration finger millet, cowpea, horse gram, transplanting of chilli

Natural calamities	Possible alternate crops and varieties
Madhya Pradesh (Malwa region)	
Initial drought: Delay in monsoon by 15th July to 31st July	Maize (Navjot, Sathi), Pigeon pea (ICPL 151, T 21,Kh-2), Til (Bhadeli, TKG 22, TKG 37),Casor (Gauch, Varuna)
Delay in monsoon by 1st August to 14th August	Til (Bhadeli, TKG 22, TKG 37),Cowpea (Pusa komal, pusa Baishakhi), Amaranthus (Co 1, Co 2), Casor (Gauch, Varuna)
Delay in monsoon by 15th August to 31st August	Safflower (JSF 1, JSF 7, JSF 37, Sharda, Sunflower (Modern, Surya, Manjira), Amaranthus (Co 1, Co 2), Casor (Gauch, Varuna)
Tamil Nadu	
Delayed onset of monsoon (rains received late in October)	Bajra (WCC 75), blackgram, greengram, sunflower (K-1)
Very delayed monsoon (First week of November	Sunflower (K-1), Gingelli (TMV 3), Senna, Coriander
Early withdrawal of monsoon	Bajra (Co 6, X 4), sunflower (K-1)
Rajasthan	
Delayed onset of monsoon	Greengram, blackgram, sesame
Early withdrawal of monsoon	Safflower, chickpea, mustard
Maharashtra	
Delayed onset of monsoon by 15 days	Pigion pea (ICPL 8863, ICPL 87119), Sunflower (EC 68414)
Regular monsoon followed by long gap (Sorghum failure)	Bajra (BJ 104), Sunflower(EC 68414), safflower (N 7), *rabi* pigeon pea (C 11)

1.5 Genetic potentiality advancement

Kharif sorghum

Sorghum is one of the most nutritious cereals, and an important dry land crop grown in marginal lands with minimum inputs. It is now recognised worldwide as a smart crop capable of providing food, feed, fodder and fuel especially under moderate inputs, and in water-deficit environments. In India, sorghum is grown both in rainy and post rainy seasons. The requirements of varieties are different for two seasons. Sorghum is bestowed with a number of mating systems which make it amenable to adapt to different breeding methods. The existence of stable and heritable CMS system made the exploitation of heterosis possible thus enabling large-scale, economic hybrid seed production in sorghum. In rainy season genetic improvement of varieties and hybrids was achieved during 60's by production of relatively short duration photoperiod-insensitive sorghums with short height by manipulating the genes for height and maturity by introducing American germ plasm. During the next five decades, remarkable progress has been achieved by diversifying the parental lines for yield, maturity, height, disease and insect tolerance and quality by utilizing indigenous and exotic germplasm.

In India, the varietal improvement programme was initiated in 1930's using the locally available genotypes. The locals were tall, late-maturing, flowering after the rainfall seized, generally photosensitive and characterized by localized adoption and low harvest index. Local x local hybridization and selection resulted in varieties having marginal increase for grain yield. Notable among these varieties developed during the early period and still under cultivation are the *CO series* in Tamil Nadu; the PJ kharif and rabi selections, *Saoner, Ramkel, Aispuri*, the *Maldandi* from Maharashtra, *Guntur and Anakapalle* series of Andhra Pradesh; the *bilichigan, fulgar white, fulgar yellow, kauvi, Nandyal, hagari, yanigar* varieties of the erstwhile Mysore state etc.

Hybrid development since 1960s*:* In 1962, the accelerated sorghum improvement project (which later became the All-India Coordinated Sorghum Improvement Project) was started and efforts were made to increase the sorghum productivity through hybrid breeding. To date, AICSIP has released 30 hybrids and 29 varieties in different product types such as kharif, rabi, forage and sweet sorghums. Initially the germplasm from the USA (kafir milo cytoplasm and other germplasm) was brought and hybrid combinations by making temperate x temperate crosses were tested. During 1962 – 1969, out of temperate x temperate and temperate x tropical crosses, three hybrids, namely CSH 1, CSH 2 and CSH 3 were released.

Introduction of CSH 1 in farmers' fields during 1960s resulted in quantum jump in the productivity and production as the hybrid responded well to improved management practices and suited to light soils and low rainfall areas. The second hybrid CSH 2, was also based on same male sterile, MS line CK 60 and a new R line IS 3691, which was also a yellow endosperm selection of Hegari from USA. Later on, a new male-sterile line 2219 B was developed and a hybrid CSH 3, was developed by using 2219 A and IS 3691 (R line of CSH 2). CSH 2 and CSH 3 could not become popular due to seed production problem. During next decade (1970-1979), three hybrids, CSH 4, CSH 5 and CSH 6 were released. Hybrid CSH 4, based on MS 1036 A had better fodder yield. The MS line of this hybrid, MS 1036 A was developed from a cross of CK 60B and PJ 8K (a local variety from Maharashtra) and the R line was a selection from exotic IS 3924. Though grain yield was tripled by utilization of exotic breeding material in hybrid programme, the grain quality of the hybrids was inferior to that of local varieties as selection pressure among temperate x tropical crosses was more on heterotic lines rather than on quality of the grain. This resulted in consumers' non-preference, price differences between locals and hybrids. Increased susceptibility to major diseases and pests were the important bottlenecks for popularizing hybrids.

Keeping these challenges in mind, new male-sterile lines were developed in different genetic backgrounds. 2077B (the MS line of CSH 5) was developed from IS 2046, a germplasm line from Senegal. Similarly converting IS 3541 from Ethiopia into a photo-insensitive dwarf line, resulted in the R line, CS 3541. The hybrid CSH 5, based on these converted lines MS 2077A and CS 3541, contributed not only to substantial yield improvement but also was an improved cultivar for grain moulds and leafy diseases as compared to CSH 1. Another achievement was towards the development of early maturing hybrid CSH 6, developed from early MS line 2219A and CS 3541 taking only 95 days for maturing. This hybrid became very popular in inter-cultivation with pigeon pea due to its geometry and earliness. Further increase in grain yield was achieved by development of hybrids like CSH9, CSH 10 and CSH 11 based on new MS line, 296 B during 1980-1989. Indian germplasm line Karad local was crossed with American material IS 3922 to develop the MS line 296B, which was the best combiner.

The MS line has a very compact panicle with more number of primary branches. CSH 9, a medium duration hybrid yields about 3.9 t/ha. This hybrid is widely adapted and extensively grown. CSH 10 and 11 developed on same MS line (296A) showed marginal superiority for grain yield.

Later, though there was no significant grain yield improvement, useful diversification for early maturity and higher fodder yield has been achieved with the release of CSH 14 and CSH 13. Though the grain yield level of this hybrid, CSH 13 is marginally improved, the fodder yield is 40% more than CSH 9. The R line of this hybrid, RS 29 that contributes to heterosis for fodder yield is developed from SC 108, an American elite line and SPV 126 (a tall mutant of CS 3541). Another, hybrid CSH 14 is an early duration hybrid, about 10 days earlier to CSH 9, with grain yield on par with the check, CSH 9. The need for diversification of female parent was felt in view of seed production problems and stagnating yield level. A high yielding hybrid CSH 16 was developed from new MS line 27A and R line C43. This hybrid showed further improvement in grain mould tolerance as the new genes from Ethiopian germplasm line IS 23549 are introduced in its R line. Later two hybrids CSH 17 and CSH 18 were released. Though the yield levels are on par with CSH 16, diversification for early maturity (CSH 17) and high fodder yield (CSH 18) was achieved. By utilizing local variety Vidisha 60-1, the MS line of CSH 18 was developed. The local variety, Vidisha 60-1 not only contributes for high stover yield but also for improved grain quality. The R line of this hybrid, Indore 12 is developed from SSV 53 and SPV 475, a variety developed from multiple crosses involving germplasm lines.

In recent times, CSH 23 an early duration hybrid was released in 2005 for cultivation in the major sorghum growing areas. It is based on the parents, MS 7A and RS 627. The next kharif hybrid, CSH 25 was a medium maturing hybrid released in 2008 and was based on PMS 28A and C 43. It has grain yield potential of 4.4t/ha and fodder yield of 12 t/ha. The latest hybrid, CSH 27 based on 279 A and CB 11, was released for Zone I. It has high level of tolerance to grain moulds. Introduction of hybrids witnessed a major change in Indian sorghum farming specifically in kharif season, which was traditionally farmed with landraces. Hybrids, CSH 1 to CSH 27, are a standing testimony of success of Indian sorghum breeding not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of resistance and quality traits against major pests and diseases. These improved cultivars played a major role in pushing up productivity and production. CSH 1, CSH 5, CSH 6, CSH 9, CSH 14, and CSH 16 show dramatic increases in productivity. From CSH 5 and CSH 6, with a yield potential of 3.4 t/ha, yield potential was raised to 3.9 t/ha in CSH 9 and to more than 4.2 t/ha in CSH 16, and CSH 25. The early duration hybrid, CSH 23 has 4.2t grain yield and 10t/ha of fodder yield and medium duration hybrid, CSH 25 has 4.4t of grain yield and 12t/ha of fodder yield. These hybrids have very high potential and yield about 8t/ha in rice fallows (non-traditional areas).

Varietal improvement: Simultaneously, varietal improvement was achieved by introducing temperate and tropical material. First variety, CSV 1 is a direct introduction of line IS 3924 from the USA. By crossing temperate and tropical germplasm, subsequent varieties CSV2 and CSV3 were developed. CSV4, which was used as restorer of 3 most famous CSH hybrids, CSH 5, 6 and 9, became a very popular variety. The variety is a converted line of an African germplasm line IS 3541, and developed by crossing it with a USA germplasm line, IS 3675. CSV 5, another variety developed from Indian local and US line IS 3687. It shows resistance for striga. CSV 10, the next variety, which became popular for high fodder value was developed from a cross between Texas elite variety SC 108 and the Indian elite variety CS 3541.

Another variety which became very popular, SPV 462 (from Coimbatore) was developed from multiple cross involving IS 2947 and IS 3687 from the USA and IS 1151 and BP 53, locals of Maharashtra and Gujarat states of India, respectively. The variety is high yielding for grain and fodder with good grain quality. CSV 13, yet another variety developed from multiple cross having exotic and local parentage is having high grain yield and medium height. The most popular kharif variety, CSV 15 is developed from SPV 462 and CSV 13. It is a dual purpose variety having grain yield equal to that of hybrid CSH 5 and fodder yield equal to that of CSH 10. The early maturing variety, CSV 17 was released in 2003. It matures in 95-97 days hence can escape terminal drought and is suitable for moisture stress areas in Rajasthan and other low rain-fall and drought prone areas with an yield potential of 2.7 t/ha of grain.

Another variety, CSV 20 released in 2009 is a medium duration variety with grain yield potential of 3.2 t/ha and fodder yield of 13 t/ha. It has high level of tolerance to shoot fly. The dual purpose varieties, CSV 23 (released in 2007) and CSV 27 (released in 2012) had grain yield of 2.8-3.0 t/ha and fodder yield of 16- 19 t/ha. CSV 27 had grain mould tolerance. The quantum yield jump which was initially obtained when hybrids were introduced has been reduced. Efforts are being made to further diversify the genetic base by bringing in new unutilized germplasm. Also, research targeting the important production constraints such as grain mould resistance and resistance to shoot pests is being given emphasis. The kharif grain is not as remunerative as that of rabi produce because the seed is not round and lustrous. Now efforts are being made to make kharif seed bold and lustrous by using guinea caudatum and durra caudatum germplasm lines.

Rabi sorghum

Rabi sorghum is highly valued for food and fodder. Rabi sorghum grains are pearly white, bold grains (100 seed weight > 3.0 to 3.5 gram) with premium market rates (> Rs.10-15 per kg) and consumed as roti (*Bhakari*) by rural as well as urban human population. Rabi sorghum is grown on 4.495 million hectares with production of 4.16 million tones with productivity of 925 kg/ha (Rabi 2009-10). Rabi sorghum is mainly grown in the states of Maharashtra (31.17 lakh ha), Karnataka (12.90 lakh ha), Andhra Pradesh (3.18 lakh ha), Tamilnadu (3.18 lakh ha) and Gujarat (0.63 lakh ha).

Constraints in rabi sorghum production: *The* rabi sorghum is mostly grown in dry land conditions on residual soil moisture in post rainy season. The productivity of *rabi* sorghum is dependent on quantity of pre-sowing monsoonal rains and water holding capacity of soil. Moisture stress is the major constraints as crop is mainly grown during post rainy season (end of September to February) on residual soil moisture. Soil moisture conservation, use of high yielding cultivars and fertilizer management plays major role in improving the productivity of *rabi* sorghum. In few pockets Maharashtra, the crop is grown in irrigated conditions with 2-5 irrigations with higher productivity upto 3.0 to 3.5 t/ha. Besides, moisture stress in GS-2 due to a unique situation of growing the crop on receding soil moisture in medium to shallow soils, susceptibility to shoot fly, charcoal rot and low temperature affecting crop growth as well as fertility restoration in hybrids are the major factors responsible for low yield.

Breeding aspects*:* Rabi Sorghum improvement: Both high grain and fodder yield under receding moisture situation are essential requirement. The resistance to shoot fly, charcoal rot, drought and cold are important for adaptation in rabi. Bold, round and lustrous grain and higher flour recovery add to the consumer acceptability.

Research on rabi sorghum to enhance productivity requires gene pools, breeding line and parental lines with different adaptation niches from those of kharif sorghum, higher dependence on rabi adapted genetic variability, specific emphasis on grain quality and fodder yield, evolution of high yielding cultivars with maturity duration suiting to different growing conditions defined by soil depth (shallow, medium and deep soils). Water retention capability and nutrient use efficiency and situation specific crop production management techniques may facilitate yield optimization under varied nutrient use soil moisture regimes. Improvement of rabi sorghum until the Nineties did not receive as much emphasis and effort as the Kharif sorghum. However, some of the recently released hybrids (CSH-15R and CSH-19R) and varieties (Central released-CSV-14R, CSV-216R, CSV-18 and CSV-22, CSV-26 and state released varieties- Sel.3, Mauli, Parbhani Moti, Phule Anuradha, DSV-4, DSV-5, Swati, Phule Chitra, Phule Vasudha, PKV Kranti, Phule Revati, Phule Suchitra) are specifically developed and recommended for rabi season. The above cultivars possess higher levels of resistance against major pest (shoot fly) and disease (charcoal rot), stringent maturity duration to suit different receding soil moisture regimes.

Although several hybrids have been developed and released for rabi season cultivation, the area covered with hybrids is almost negligible. Lack of appropriate hybrids with acceptable grain quality adapted to different agro-ecological situations of rabi season characterized by terminal drought, low temperatures and biotic stresses like shoot fly infestation is a major constraint for higher productivity. Certain levels of thermo insensitivity are essential in rabi cultivars for better adaptability. Grain quality is also as much important as the grain yield. The quality bench mark is that of the popular land race, Maldandi 35-1. In adaptability criteria such as shoot fly resistance as well as the grain quality aspects, the varieties are superior to hybrids. Unlike in the case of Kharif, it appears rabi varieties have better preference over rabi hybrids for reasons of adaptability and grain quality. Possible development of genetically engineered cultivars with resistance to shoot fly may offer opportunity to advance rabi planting and avoid problems associated with terminal moisture stress and low temperature.

Status and scope for transgenic and genomics

The application of transgenics and genomics for sorghum genetic improvement are essentially focussed on trait improvement- including improving resistance to complex traits – biotic (shoot fly, grain mould, stem borer, aphids, etc.) and abiotic (drought, salinity), improving quality (grain for food, poultry and industry, fodder, stalk for ethanol production) and novel bio-products. In addition, research aimed at predicting heterosis and incorporation of apomixis is being pursued using new tools to help farmers realize the maximum yield potential at minimum cost.

One important dimension of accomplishing traits of interest including novel ones in sorghum cultivars is the deployment of transformation technology to transfer the genes of interest or regulate the expression of host genes. The system has achieved a very high degree of success in producing genetically transformed plants for an array of genes of interest that add value to existing cultivars. The Bt transgenic sorghum already developed not only holds promise as an important source of resistance to stem borer, but exemplifies the possibilities of incorporating new genes into sorghum for innumerable end-uses. A similar approach would be a major option for improving resistance to shoot fly, grain mould, aphids, etc. if suitable candidate genes are identified. The progress in improving these traits had been limited by using other approaches. The transgenics would also help in alleviating the effects of abiotic stresses, augmenting the quality of grain, fodder, stalk, etc. using appropriate candidate genes. Research in functional genomics of sorghum would pave way for identifying the sorghum candidate genes for such manipulations.

Sorghum genomics have made rapid advances during the past decade. The sorghum genome has been sequenced and important gene transcripts and regulatory mechanisms are being deciphered on large scale worldwide. Molecular markers have been identified in plethora of mapping populations and robust consensus genetic maps are in place. Large genomic regions linked to important traits are being identified and validated. Initiatives for implementing precision-breeding using molecular marker-based selection for traits under complex genetic control such as resistance to shoot fly, post-flowering drought and grain mould are on. Efforts are also on to identify genes and alleles associated with abiotic stresses and quality using allele mining approach.

The genetic diversity in sorghum provides an opportunity to search for new genes and alleles that are responsible for conferring desirable phenotypes. The development of large mutant population as a reverse genetic resource is envisaged to unravel the expression of battery of genes and the mechanisms of their regulation. The advent of affordable next-generation sequencing holds immense possibilities for increasing our understanding of complexity of genetic control of traits of interest, only limited by our imagination. Besides, the unexplored but potential gene pool of the wild relatives would be introgressed for improving agronomic performance of cultivated sorghum. The challenges of adventuring into the exciting task introgressing useful traits from related cultivated species such as sugarcane and maize would be addressed.

Status and scope for bio-fortification in respect of iron, zinc & calcium in the grains

The magnitude of micronutrient deficiency in India is alarming particularly among children, women of reproductive age, and pregnant and lactating women (Sharma 2003). The intake of micronutrients in daily diet is less than 50% RDA in over 70% of Indian population (NIN 2002). Iron deficiency anaemia is very common amongst Indians and its prevalence varies from 75% among children and women to 45% among adult males (Narsinga Rao 2003). The prevalence of zinc deficiency has not been adequately investigated, partly due to lack of suitable biomarkers. Using disability adjusted life years (DALYs) technique; it has been found that zinc deficiency in India is a highly relevant health problem and responsible for a loss of 2.8 million DALYs (Stein et al. 2007).

Sorghum is the fourth most important cereal consumed in India. Sorghum is the main source of dietary energy in central India. It contributes around 50% of the total cereal intake (75 kg grain per head per year), especially by rural consumers in the inland central region and inland eastern region of Maharashtra and the inland northern region of Karnataka. In terms of nutrient intake, sorghum accounts for about 35% of the total intake of calories, protein, iron and zinc in the dominant production/ consumption regions (Rao et al., 2006). Consumption is the highest (75 kg grain/head/year) by rural consumers in the inland central region of Maharashtra, followed by the inland eastern region of Maharashtra and inland northern region of Karnataka (Rao et al. 2006). Sorghum is a cheap source of energy, protein, iron and zinc next only to pearl millet.

Discovery of variability for grain iron and zinc in sorghum is underway at different institutes. Sorghum grain has a nutritional profile better than that of rice, the chief staple food of majority (Hemalatha et al. 2007), but the bioavailability of iron and zinc in sorghum is poor compared to other cereals and pulses owing to high fibre content. Reports from NIN, Hyderabad indicate that sorghum is superior to rice for contents of protein, minerals and iron, while the values are on a par or marginally better than that of wheat. Sorghum has limited information base and research related to bio-fortification. Though preliminary studies at ICRISAT have indicated limited variability (Reddy et al., 2005) for grain iron and zinc, significant genetic variability coupled with high correlation between grain iron and zinc contents were observed among parental lines, varieties and germplasm accessions from core collection (Reddy et al., 2006, Kumar et al., 2010, Sanjana Reddy et al., 2010). The variability for b-carotene content was low and there are little reports on variability for calcium content. Popular rabi season sorghum varieties preferred for food use in India possess low grain iron and zinc contents. In contrast, the kharif hybrids possess better iron and zinc contents (up to 44 ppm iron and 33 ppm zinc). Significantly high and positive correlations were observed for grain iron (0.9) and zinc (0.8) contents estimated between grain obtained from open-pollinated and selfed panicles. Significant and fairly higher positive correlation between grain iron and zinc contents (r = 0.6-0.8) and their poor correlation with agronomic traits such as days to 50% flowering and plant height and with farmer-preferred grain traits such as grain size and grain hardness indicated the possibility of delivering high iron and zinc contents in cultivars with farmer's preferred traits (early maturity, high yield potential, and bold lustrous grains). Only weak genotype × soil fertility interaction has been reported for grain micronutrients. Pre-breeding feasibility studies at ICRISAT have indicated the possibility of introgression breeding for micronutrient contents in sorghum (Ashok Kumar et al. 2012).

Studies were initiated at DSR, Hyderabad to characterize genotypes for levels of micronutrients, and other nutritional/anti-nutritional factors. Significant variation was observed for micronutrient contents and nutritional factors like polyphenols, phytate, cyanogen, trypsin inhibitor and anti-oxidant activity among the 200 sorghum genotypes comprising hybrid parents, popular cultivars, breeding lines and selected germplasm accessions tested at the Agharkar Research Institute (ARI), Pune (Agte et al. 2009). Good range for iron and zinc contents has also been observed among 60 yellow pericarp sorghum and elite lines with low amylose content. All these results have to be confirmed further. Preliminary studies on testing the stability of grain iron and zinc contents across growing conditions, and the effect of external application of iron and zinc fertilizers on grain micronutrient status were taken up.

Bio-fortification approach is potentially more sustainable than fortification or supplementation programs. The development of sorghum cultivars with elevated levels of micronutrients can provide a cost-effective and sustainable solution to this recurring problem. The intake of iron and zinc is below the recommended dietary allowance (RDA), particularly in low-income rural households in sorghum consuming regions. Targeting micronutrient-dense sorghum cultivars to these regions would help in alleviating micronutrient malnutrition. Hence, development of bio-fortified sorghum varieties would help in enhancing the micronutrient availability and uptake in the target population mainly dependant on sorghum as staple food.

1.6 Seed Scenario

Table-13: State-wise SRR (%) of Sorghum during 2006 to 2012

Sl. No.	State/Cultivar	2006	2007	2008	2009	2010	2011	2012
1.	**Andhra Pradesh**							
	Variety	63	54	49	58.33	61.48	62.60	64.24
	Hybrids	100	100	100	100	100	100	100
2.	**Karnataka**							
	Variety	26	26	25	30.73	33.22	29.54	29.44
	Hybrids	100	100	100	103.81	100	99.55	99.99
3.	**Tamil Nadu**							
	Variety	6	6	11	10.60	9.93	16.44	14.22
	Hybrids	-	-	-	-	-	-	-
4.	**Gujarat**							
	Variety	-	-	-	-	-	-	-
	Hybrids	100	100	100				
5.	**Maharashtra**							
	Variety	10	10	13	12.60	15.00	13.5	16.53
	Hybrids	100	100	100	99.89	98.51	101.5	99.34
6.	**Rajasthan**							
	Variety	7.50	8.22	9.01	8.72	25	21.89	26.10
	Hybrids	-	-	-	-	-	-	-
7.	**Madhya Pradesh**							
	Variety	14.28	13.28	13.27	15.85	15.96	20.98	13.65
	Hybrids	-	-	-	-	-	-	-
8.	**Uttar Pradesh**							
	Variety	11.69	17.31	21.11	19.44	34.6	24.21	24.25
	Hybrids	-	-	-	-	-	-	-
	ALL INDIA							
	Variety	19.37	19.87	26.16	-	-	-	-
	Hybrids	-	-	-				

Source : Seednet India Portal

1.7 Recommended package of practices

Recommended package and practices by ICAR

S. No	Operation	Details	Crop: Sorghum
1	Time of sowing	*Kharif:*	3rd week of June to 1st week of July with onset of monsoon.
		Rabi:	15 September-15 October
		Summer:	3rd week of January to 1st week of February
2.	Method of sowing	Manual (%)	100%
3.	Seed	Seed rate:	8-10 kg/ha
		Row to row distance	45 cm
		Plant to plant distance	12-15 cm
		Ideal plant population/ha	1, 80,000 (kharif and irrigated rabi)1,35,000 (raifed rabi under receding soil moisture condition)
		Seed treatment	Imidacloprid (70 WS) 3 g + carbendazim 3 g /kg seed or thiamethaxam (70 WS) 4 g/kg seed.
		Fungicides (Name & Dose)	• Carbendazim or thiram 3 g /kg seed • Seed dressing with sulphur @4g/kg seed or Thiram 75 @ 3 g/Kg seed control seed-borne diseases • Seed dressing with Ridomil25@ 1g a.i./kg control systemic infection of downy mildew
		Bio-fertilizer (Name & Dose)	Phosphate solubilizing bacteria (PSB): 50 g/kg seed. Azotobactor: 25 g/kg seed
4.	Fertilizer dozes (kg/ha)	***Kharif***	
		Urea	140 kg/ha,(if phosphorus in given through DAP) or 175 kg/ha,(if P is given through SSP).
		DAP	90 kg/ha
		SSP	250 kg/ha (if DAP is not available)
		Gypsum	10-15 t/ha (depending up on soil pH).
		Micro-nutrient	Soil application of Zinc sulphate 25 kg/ha, Ferrous sulphate 25 kg/ha based on soil test. Foliar spray of 0.50% zinc sulphate and Ferrous sulphate 2-3 times is also recommended.
		Bio-fertilizers	Vermicompost @2.5 t/ha
		Manures'	FYM 10 t/ha alternate years
		Rabi/summer	
		Urea	*Irrigated condition*: 140 kg/ha,(if phosphorus in given through DAP) or 175 kg/ha,(if P is given through SSP). *Rainfed*: 75 kg/ha,(if phosphorus in given through DAP) or 90 kg/ha,(if P is given through SSP).
		DAP	90 kg/ha (irrigated); 50 kg/ha (rainfed).
		SSP	250 kg/ha for irrigated and 125 kg/ha for rainfed (if DAP is not available).
		Gypsum	10-15 t/ha (depending up on soil pH).

S. No	Operation	Details	Crop: Sorghum
	Fertilizer dozes (kg/ha) contd….	Micro-nutrient	Soil application of Zinc sulphate 25 kg/ha, Ferrous sulphate 25 kg/ha based on soil test. Foliar spray of 0.50% zinc sulphate and Ferrous sulphate 2-3 times is also recommended.
		Bio-fertilizers	Vermicompost @2.5 t/ha
		Manures'	FYM 10 t/ha alternate years
5.	Weeds control	Name of the major weeds	***Grasses***: *Digitaria sanguinalis* (L.) Scop. (Crab grass), *Dactyloctenium aegyptium* L. (Crowfoot grass), *Eleusine indica* (L.) Gaertn. (Goose grass), *Echinochoa colona* Link. (Jungle rice), *Sorghum halepense* (L.) Pers.(Johnson grass), *Setaria viridis* L. (Green foxtail). ***Broad-leaved:*** *Commelina benghalensis* L. (Tropical spider wort), *Celosia argentea* L. (White cock's comb), *Trianthema portulacastrum* L. (Horse purslane), *Boerhaavia diffusa* L. (Hog weed). ***Sedges***: *Cyperus rotundus* L. (Purple nut sedge) ***Parasitic weed***: *Striga asiatica* (Witch weed)
		Control measures	Use of pre-emergence herbicide followed by manual weeding/hoeing/inter-cultivation at 30 days after sowing.
		Name of the herbicide	Atrazine
		Doses (lit/kg)	0.50kg ai or 1.0 kg commercial product (50% ai)/ha
		Time of Application	Pre-emergence (within 2 days after sowing)
		Method of application	Knapsack sprayer fitted with flat-fan nozzle with spray volume of 500 litre water/ha
6.	Disease management	Name of the major diseases /Pests Control measures Name of the pesticides Doses (lit/kg)	**Diseases:** **Grain mould**· ● Avoid cultivars that are likely to be caught in heavy rains.· ● Harvesting of panicles at physiological maturity and artificial drying in community dryer. · ● Sprays panicles with fungicide (Captan 0.3%, Tilt 0.2%) or bio-agents (Fluorescent Pseudomonas 10^7 cfu/ml) reduce mould and improve seed quality. **Anthracnose** ● Use of clean seed, destroying plant refuse, crop rotation and removal of susceptible weeds (Sudan grass and Johnson grass). ● Use of resistant cultivars **Downy mildew** ● Deep ploughing before planting to destroy oospores ● Rogue out infected plants ● Seed dressing with Metalaxyl/ Ridomil25@ 1g a.i./ kg

S. No	Operation	Details	Crop: Sorghum
	Disease management contd....		**Sorghum stripe virus** ● Practice of clean cultivation. Removal of weeds from the bunds ● Control of insect vector by spraying Imidachlorpid @ 1.5 ml/L water **Charcoal rot**· ● Conservation of soil moisture: optimum plant density, straw mulching and mixed cropping. ● Use of early maturing varieties. ● Seed treatment with fluorescent *Pseudomonas* (10^7 cfu/ml) reduce incidence. **Ergot/ Sugary disease** ● Ensuring synchrony of flowering (A and R lines) in seed production plots ● Early sowing, removal of collateral host from the field bunds. ● Mechanical removal of sclerotia from seeds ● Two spray of Tilt 25% EC @ 0.2% starting from flowering at 10 days interval. **Leaf rust**· ● Use clean seeds, rotate crop, destroy the plant refuse, and use resistant cultivars with tan plant pigment. ● Spraying of Dithane M 45 @ o.2% thrice at 10 days intervals starting at 30 days crop.
		IPM	**IPM for Disease:** Integrated management of kharif sorghum diseases is through cultural practices like deep ploughing, timely sowing of healthy seeds, cultivation of genetically resistant hybrids such as CSH14, CSH16, CSH17, CSH18 and varieties CSV 13 and CSV 15, need based chemical seed treatments and sprays are recommended.
7	Pest management	Name of the major Pests, Control measures, Name of the pesticides & Doses (lit/kg)	**Pests** **1. Shoot fly** ● Early sowing (15 June-15 July) in Kharif and (15 Sep to 15 Oct) in Rabi to avoid shoot fly incidence. ● Use 1.5 times more seed rate (upto 12 kg/ha) remove shoot fly damageid seedlings at the time of thinning. ● When the shoot fly damage reaches 10% of the plants with dead hearts, the crop may be sprayed with Cypermethrin 10 EC (750 ml/ha) or quinalphos 35 EC (350 g a.i./ha).

S. No	Operation	Details	Crop: Sorghum
	Pest management contd....		**2. Stem borer** ● Early sowing (15 June-15 July) in Kharif and (15 Carbofuran granules @ 12-15 kg/ha may be applied in the leaf whorl. ● or Early sowing (15 June-15 July) in Kharif and (15may be sprayed with quinalphos 35 EC (350 g a.i./ha). **3. Sugarcane Aphids** ● Dimethoate @ 500 ml/ha may be sprayed if less infestation or ● Spray metasystox 35 EC @ 500 ml/ha **4. Shoot bugs** ● Dimethoate @ 500 ml/ha may be sprayed if less infestation or · ● Spray metasystox 35 EC @ 500 ml/ha. **5. Sorghum midge** ● Crop may be sprayed at the 50% flowering stage if (1 midge/ panicle observed) with quinalphos 35 EC (350 g a.i./ha) or Cypermethrin 10 EC (750 ml/ha). **6. Earhead bugs** ● If observe, 1 to 2 bugs per panicle, the crop may be sprayed with quinalphos 35 EC (350 g a.i./ha) or Cypermethrin 10 EC (750 ml/ha) at the completion of flowering and at the milk stage.
		IPM	● Adopt synchronous and timely/early sowings of cultivars with similar maturity over large areas to reduce the damage by shoot fly, midge, and head bugs. ● Intercrop sorghum with soybean (2:4 ratio). Apply seed treatment of Thiamethoxam 70 WS @ 3 gm/ kg of seeds. ● Intercrop sorghum with safflower (2:2 ratio) with seed treatment either of thiamethoxam 70 WS @ 3 g/kg seed or imidacloprid (@ 5 g/kg of seed and one spray either quinalphos 35 EC (350 g a.i./ha) or carbofuran 3G at 35 DAE. ● Destroying stubbles before the onset of monsoon reduces the carryover of stem borers and midge.
8	Threshing	*Manual (%)*	100
9	Any Innovative technology adopted	Sorghum	Sorghum cultivation under zero tillage in rice-fallows of coastal Andhra Pradesh

1.8 Cropping System

Major crop sequences / rotations recommended by AICRP

Intercropping

- Sorghum intercropped with pigeon pea, green gram, soybean and sunflower are beneficial.
- Sorghum and pigeon pea are to be sown in the 2:1 row ratio without additional fertilizers.
- Medium to short duration sorghum genotype like CSH 16, CSH 17 and CSH 18 are suitable.
- In intercropping, spraying of weedicide/herbicide is not recommended.
- Sorghum and fodder cow pea in 2:2 row provides green fodder, helps to improve soil fertility and check weed growth.

Sequence cropping

- After *kharif* sorghum, a sequence crop in *rabi* like chick pea, safflower and mustard are found most suitable in most of the situations.
- These sequence cropping are found more profitable in areas which receive rainfall above 700 mm and having moisture retentive medium to deep black soils.
- *Kharif* sorghum should be harvested at its physiological maturity to gain about one week time in planting the next crop.

State-wise recommendations

Sorghum-based intercropping systems	AICSIP Centre (State/region)
Sorghum+ pigeonpea (2:1 or 3:3)	Dharwad (Karnataka), Parbhani (Maharashtra), Palem (Andhra Pradesh), Coimbatore (Tamil Nadu), Indore (Malwa region of MP))
Sorghum+ soybean (3:6 or 2:4)	Parbhani (Marathwada region of Maharashtra), Akola (Vidarbha region of Maharashtra), Indore (Malwa region of Madhya Pradesh),
Forage sorghum +cowpea /clusterbean (2:2)	Udaipur (Rajasthan), Hisar (Haryana), Ludhiana (Punjab), Pantnagar (Uttaranchal)
Sorghum-based crop rotations	
Sorghum-chickpea/safflower	Rainfed areas (medium and deep soils)of Karnataka, Maharashtra and parts of MP
Sorghum (forage)-wheat	Some parts of Irrigated areas of northern and central India

Impact of crop with respect to uptake of nutrients, soil health & underground water

Nutrients: Sorghum is generally grown under less favourable conditions and meagre amounts of fertilizers are applied. The average per hectare use of fertilizer in sorghum was 47.5 kg/ha (29.2 kg/ha N, 14.2 kg/ha P_2O_5 and 4.1 kg/ ha K_2O) as compared to 60.2 kg/ in maize, 119.1 kg/ha in paddy and 136.7 kg/ha in wheat (FAO, 2005). Sorghum crop producing 5.5 t/ha grain removes a total of 335 kg nutrients (149 kg N + 61 kg P_2O_5 + 125 kg K_2O)/ha from soil. The response (kg grain/kg nitrogen applied) of rainfed sorghum during rainy season varied from 21.7 kg in alfisols, 18.32 kg in vertisols, 11.9 kg in molisols and 20.15 kg in entisols (Tandon and Kanwar, 1984). The response of phosphorus (kg grain/kg P_2O_5 applied) varies with soil types in order of

Alfisols (17-32 kg) >Entisols (11-34 kg) >Vertisols (7-27 kg). In post-rainy crop, a response of 11 kg grain/kg P_2O_5 was obtained in Vertisols. Potassium deficiency may not be a serious problem for sorghum. Among micronutrients, deficiency of zinc (Zn) and iron (Fe) is more widespread in sorghum growing areas. Deficiency of Zn and Fe can be corrected either through soil application (20-25 kg/ha) of respective sulphate forms or through foliar application (0.20-0.50%).

Water: Although sorghum is a drought tolerant crop, it responds to irrigations and is well suited for limited irrigations. Sorghum crop requires 425-610 mm of water for getting higher yield. Roots of mature sorghum plant can extract soil moisture from up to 2 m of soil depth, although higher yields are obtained when moisture is available in the top 76 cm of soil. Sorghum produces 3.3 g of biomass per kg water used in evapo-transpiration. It requires 22% less water than maize to produce a unit of dry matter. The water-use efficiency in sorghum varies from 7.5 to 9.0 kg/mm/ha depending upon soil types.

1.9 Crop products

Sorghum is traditionally consumed in the form of unleavened pan cake (bhakari). Grain is eaten by human beings in India either by breaking the grains and cooking it in the same way as rice or by grinding it into flour and preparing '*Chapatis*'. In southern India, it is consumed in the form of Sankati, Annam and Kanji (thin porridge). Popped sorghum and sorghum noodles are important snack foods. However, Sorghum can be replaced with rice or wheat in many common food dishes that are common made. Sorghum grains are polished with a pearling machine and processed into flour as well as rawa (suji) of different particle size.

Sorghum food consumption has many potential health benefits such as high anti-oxidant levels, improved cholesterol profiles of the consumer, and as a source of safe food for persons with celiac disease. Sorghum grain have high fibre content, moderate digestibility, rich mineral content compared to other cereals such as rice and wheat. Therefore, sorghum foods are recommended for diabetic and jaundice-affected persons and for fighting obesity.

The proximate composition of sorghum grain is given in **Table-14.**

Table-14: The proximate composition of sorghum grain (per 100g)

Ingredient	Quantity	Ingredient	Quantity
Protein (g)	10.4	Lysine(g)	2.0
Carbohydrates(g)	72.6	Methionine(g)	1.4
Fat(g)	1.9	Cystine(g)	1.4
Crude fibre(g)	1.6	Phenylealanine(g)	4.9
Mineral matter(g)	1.6	Tyrosine(g)	2.7
Calcium(g)	25	Threonine(g)	3.1
Phosphorus (mg)	222	Tryptophane(g)	1.1
Isoleucine(g)	3.9	Valine(g)	5.0
Leucine(g)	13.3	Hstidine(g)	2.1

Alternate use of sorghum

The main industries currently using sorghum in India are poultry, dairy and alcohol distilleries. In poultry sorghum is a good substitute for maize because it is relatively cheaper. The feed for dairy is an additional advantage. A fair demand also exists for sorghum in Alcohol distilleries. Recent studies by ICRISAT concluded that sorghum can effectively replace maize. However, relative price and availability are criteria. If sorghum price is 80% of maize price manufacturers are willing to substitute with sorghum. More than above projected levels, the demand for sorghum as potable alcohol and ethanol (bio-fuel) is going to exceed.

Value added Product of Sorghum

The important traditional/fast food and industrial usages of sorghum is given below:-

Food products	Industrial products
Roti, *ugali*, popped sorghum, malt food, snack/roasted mix grains.	Malting, high fructose syrup, starch, *Jaggery*, bakery, value added products for diabetics poultry and animal feed.

Besides, the cultivation of grain sorghum, Northern States like Haryana, Punjab and Western UP is primarily done for fodder purposes. A number of varieties/hybrids of sorghum have been developed particularly for fodder purposes. Beside these sorghum grain and stalk of sweet sorghum is used as value addition purposes;

Popping: Grain sorghum, the most important cereal after rice and wheat is considered as less economical. However, application of suitable processing technologies may add value to the crop. Popping is one such technique which improves the quality of the grain. Grain popping is one of the popular dry-heat (high temperature short time – HTST) processing methods followed to prepare ready-to-eat products from sorghum. The popped grains contain pre-gelatinised starch and possess highly desirable aroma and crunchy texture. Since, popped Sorghum contain the bran layer, they are good source of dietary fibre and nutraceuticals. *Normally, the expansion volume of the popped Sorghum ranges from 7 – 8 ml/g.* The varieties with hard endosperm and medium thick pericarp exhibit superior popping qualities. The lipases get denatured during popping and hence, popped products have better shelf life, provided they are stored in air tight containers. This is highly advantageous with respect to pearl millet as processed pearl millet has very low shelf life. HTST treatment ensures that popped foods are generally microbially safe. Popped grains serve as snacks after seasoning and could be used for preparation of sweet meats such as *Laddu* or *Sattu* and *Chikki* or could be blended with toasted or puffed legumes, oilseeds and jaggery or sugar to prepare delicious and nutritionally balanced convenience foods for growing children and lactating mothers.

Expanded grains: Expanded rice or *Murmura* is a very popular product. But similar products from other cereals are rare. The reason being preparation of such products need elaborate processing of cereals, viz. parboiling and pearling or the grain before subjecting to HTST treatment. The recent R&D work has established the feasibility of preparation of expanded grains from millets. In fact, such a product from *Bajra* is in the Indian market. Expanded grains are novel and high value products and can find application as ingredients for snacks and crispy in confectioneries and also as thickener in soup mixes.

Flaking: Cereal flakes are popular snacks and are largely prepared from rice or corn. Flakes from Sorghum could be produced adapting the normal cereals flaking methods. However, because for the rigid endosperm texture,nearly spherical shape and smaller size heavy duty roller flaker is essential for flaking, unlike the edge runner used for flaking of rice. The process inactivates the lipase leading to better shelf-life of the product. The flakes could be toasted or expanded by hot air or sand which may serve as snacks or supplementary food for the obese and calorie conscious people. After toasting they could be conveniently used as ingredients of muesli and such other products.

Noodles/Vermicelli: Vermicelli/noodles being convenience products are gaining popular in the country. They are mostly prepared from wheat in east and from rice in east. Of late, rice vermicelli is receiving recognition in India also. Sorghum is non-glutinous cereal and hence need special pre-treatment to extrude into strands. Efforts to prepare noodles from these grains have been fruitful but till date such products are not produced on commercial scale. There is a need to develop a simple technology for production of vermicelli from sorghum.

Roti/Tortilla: Roti is a popular tradition food in India which is made from cereal or millets flour. The “Eatrite” brand jowar rich multigrain atta is prepared from careful blend of 100% natural whole grains jowar, wheat, ragi, black gram dhal and fenugreek in the right proportion. Different grains have varied advantages, sorghum and other millets provide additional minerals, dietary fiber and micronutrients from multigrain roti’s than the normal roti made from wheat. Addition of wheat to the dough makes it pliable and allows better shaping, retaining the original roti taste. The multigrain atta produced by “Eatrite” brand has more jowar flour (>50%) than the other brands which are available in the market. It is more suitable for consumption in the present health scenario to combat free-radicals, which cause obesity and other chronic diseases, as it is rich in phytochemicals and micronutrients.

It is needless to mention here that, the normal Indian consumer prefers chapati or roti to bread, hence ready-to-warm rotis from Sorghum that, the very good market. Alternately, pre-processes roti flours that enable mixing with cold water and rolling similar to wheat flour will offer convenience to time starved consumers.

Bread and Bakery: It has been very well documented that, Sorghum flours alone are not suitable for preparation of bread and bakery products similar to wheat. But they can be used to prepare composite flours consisting of wheat and Sorghum including millets flours. However, only up to 30% sorghum and millets could be used along with wheat for preparation of such products without affecting the texture and taste. In fact, the products from the composite flour would be nutritionally superior to wheat based products due to the phytochemical contents from Sorghum. However, there is need for developing the processes for preparation of bread and bakery products from sorghum similar to the Scandinavian rye bread. Obviously, such predicts would be gluten free and fine widespread application as health foods.

Starch, Dextrins and Ethanol: Sorghum is basically starchy grains and has potential for industrial level production of starches for food and allied application. Technologically and economically sorghum has the potential for the production of such products.

Ethanol : Alcohol is widely used industrial raw material. It can be produced both from the juice of sweet stalked sorghum as well as from grain and thus whole plant utilization can be promoted. The complete technology to produce alcohol from grain is perfected by AICSIP centre, PDKV, Akola (Maharashtra) and from sweet sorghum by Nimkar Agriculture Research Institute (NARI), Phaltan-415523(Maharashtra) and AICSIP Centre at MAU. Parbhani (Maharashtra). At NARI , unsterilized juice without addition of any nutrients was successfully fermented by using *Saccharomyces cerevisiae* strain NCIM 3319. The average fermentation efficiency obtained was 90% and the fermentation was completed between 48-72 hours. The juice containing 10-11% (w/w) total fermentable sugar gave 6% (v/v) alcohol yield i.e. 1000-2000 l/ha/ season of 95% (v/v) alcohol. Other than industrial uses, technology for its utilization in lantern and in wickless stove has been developed at NARI. However, highest yield of ethanol (10.33%. v/v) was obtained at the end of 72 hours, of fermentation using *S. cerevisiae* strain NCIM 3281. At PDKV, Akola total alcohol yield (stalk juice + grain) ranged from 2.19 to 29.99 hecto-litres. Autoclaving step could be replaced by acidification of juice to pH 3.0-3.5.

Liquid glucose and dextrose - Monohydrate production from grain: The process of glucose / fructose and alcohol production from grain is same up to liquidification. The liquid glucose is an industrial consumer product. It is mostly consumed by confectioneries, bakeries, biscuit, beverages and pharmaceutical industries in addition to its use for antibiotics , organic acids, steroids, vitamins, polyols, alcohol, sorbitol etc. production.

Spirit: The grain of commonly grown sorghum cultivars contains 65-71% starch. At present this starch is hydrolysed to yield simple sugars, which are then fermented to yield alcohol. About 20—25% of the starch is lost during the process, as it remains bound to fibre and is difficult to extract. Whole grain utilization was therefore tried, using Termamyl-120L (a heat stable alpha amylase, produced by No Vo Nordisk Als, Bangalore, India) for liquefication and AMG 300 L (an amyloglucosidase , also produced by No Vo Nordisk Als) for saccharification of the four methods tired, simultaneous saccharification and fermentation at room temperature (28 + 2^{0}C) was most efficient.

A laboratory model has been made of a compact glass column that could yield 184-190^0 proof alcohol with 92.2% ethyl alcohol. From 25-30% grain slurry, an ethanol concentration of 11-12% (v/v) was obtained , and results indicated that 384 litres of ethanol could be produced from one tonne of sorghum. Discoloured grains with a threshed grain mould rating (TGMR) of 3.0 on a 1 to 5 scale, were used to produced alcohol using a method that combines saccharification and fermentation. The reduction in alcohol yield could be correlated with the loss of starch in grains due to moulds.

Syrup Production: The sweet sorghum variety with relatively high reducing sugar (glucose, fructose) may be more suitable when TSS reaches above 14 degrees. MPKV Rahuri has developed a useful method. The procedure includes filtering of row juice, centrifugation and addition of alpha amylase (50 PPM) to remove juice. These varieties have a potential of 400 q/ha green cane, 15000-18000 l/ha juice and 18-9 TSS (brix) and even 20q/ha grain in 120-125 days. Thus can give 40-50 q of syrup or 30-35 q of jaggery per ha. The appropriate stage for crushing is when the crop reaches 18^0 brix. The leaves are removes before crushing which is a nutritious fodder. The juice and jaggery yield can be increased substantially by improving crushing efficiency to 50-60% using impurities and starch: boiling of juice on slow fire in iron pan with zinc layer, addition of okra (bhindi) mucilage (1.0-1.5 kg(okra plant extract @ 750 litres of juice in boiling pan to remove non sugary matter, removing of scum with perforated ladle on and often , add filtered solution of single super phosphate@150-200g made in 5 litres of water in boiling juice in 3 to 4 instalments to avoid inversion of sucrose to glucose and for obtaining golden yellow color of jaggery and transparent syrup. The syrup is formed at 103-104^{0}C temperature of boiling juice. For safe preservation of syrup, mix thoroughly 50 g of sodium benzoate in 100 litres syrup. After cooling the syrup to room temperature, the bottling is done. The bottles/ containers should be sterilished in boiling water, filled and sealed. A complete methodology is also available at NARI. The sorghum syrup may look similar to honey and contain 5% (w/w) sucrose and 65% reducing sugars. Calcium Vitamin C and Nicotinic acid may be 160, 11.5 and 153 mg per 100 g respectively. It can be used as table syrup, bread spreads and in salad dressing, cakes and biscuits, ice cream topping etc.

Jaggery production: high TSS and ratio of sucrose to reducing sugars greater than 9 gave good quality jaggery. Proper scum removal was found to be most important parameter in jaggery production from sweet sorghum. Solidification/ball formation stage is attained generally at 110-112^{0}C. Further pour semisolid material from the boiling iron pan in cement or porcelain ten/pan, stir slowly but oftenly and allow to cool. More vigourous working of the concentrated mass during cooling period gives better colour. One can try method applied to sugarcane and can make both solid and liquid jaggery. Addition of alpha-amylase and centrifugation of addition of 1 g of crystalline sugar per litre at boiling can give jaggery comparable to that from sugarcane juice. There is comparative report that jaggery prepared from the juice of sweet sorghum contained 78.1 % sucrose and 8.8% reducing sugar as compared to 84.2%sucrose and 7.5% reducing sugar in jaggery produced from sugarcane. The white sugar can also be manufactured from sorghum independently as well as along with sugarcane juice without disturbing manufacturing process. A thumb rule in sugar technology states that every unit of non-sucrose impurity of juice reduces the recovery by 0.4 units. The dissolved solids in sweet sorghum juice contain 70-75% sucrose and 25-30 % non sucrose impurities. Of about 10% sucrose in mature stalk, poses a problem for quality jaggery/syrup production. IISR studies showed encouraging results with use of a new flocuulent , Floc 53. Removal of maximum amount of starch (93.7%) could be obtained by adjusting the pH of the juice to 8.5 and heating it to 55^0C in the presence of 500 PPM flocculent. Addition of enzyme from barley malt in sweet sorghum juice may remove starch to an extent of 96.9% . The starch can be removed (87.24%) by centrifugation and addition of alpha amylase (50 PPM). It is estimated that a net profit of ' 7500 from jaggery and grain can be obtained in six months period. Syrup production may give 20-25% more net profit over jaggery.

Starch : Grain sorghum is similar to maize in its composition and properties. Thus the technology developed to extract starch from maize can be used for sorghum with a little modification. Recovery of starch from sorghum is 5-8% less than maize since some starch goes with crude fibre. Since sorghum costs less than maize ,the profit margin in sorghum based starch manufacture are relatively high. There are good prospects as area under tapioca from which about 50 % of starch is produced is getting reduced. Of the three extraction methods tried in the laboratory, lactic acid (1 %) added during seeping gives comparatively higher starch yields. The starch extracts is white in colour, with a Barbender amylograph similar to maize starch. Sorghum starch can be used for a number of purposes: in manufacture of binders, glue and thickeners, as a functional additive in the processing of synthetic and (mixed with maize starch if necessary) in the sizing and printing of fabric. More research in needed to develop these and other forms of sorghum starch utilisation. Sorghum germ oil contains low levels of stearic (4%) and palmitic (10%) acids, and thus has a large potential market in hydrogenated oil and soap industries. Other by-products such as oil cake, glutelin and crude fibre can be used as feed. Discoloured/ rain damaged grain and grain with more corneous endosperm where starch recovery is less can be processed for sugar and alcohol production.

Semolina: Semolina was prepared from sorghum grain in a commercial wheat flour mill. The grain was dehulled using carborundum abrasive rollers. Of the five grain cutting machine sections of the roller mill, only three were used and a good quality sorghum semolina was successfully produced.

Malting: Malting is one of the very early biotechnological processes adopted for cereal processing for food and brewing. Although, barley has the place of pride for malting, sorghum malting is also practiced extensively. While sorghum malting is largely adapted for brewing in Africa, where it is carried on industrial scale.

Cleaned sorghum grains were allowed to germinate for up to 96 h. kilned degermed and then roasted in a hot air oven until they were brown. On cooling, the grains were coarse ground. To prepare sorgho vita the following ingredients were used (w/w): Malt 60%, milk powder 10 %. Sugar 25%, chocolate powder 1.55, cocoa 1.5% and minerals 2%.

To prepare beer, 50g of malt were mixed in 450 ml of water, boiled for 2 hours and then filtered. The filtrate was adjusted to acidic pH and an inoculum of 4-5% *Saccharomyces uvarum* (NCIM 3305) were added. Fermentation was allowed to proceed for 45 hours at 15°C, after which the mixture was filtered and incubated at low temperatures. No adjuncts were used in this method. The clear liquid obtained contained 5-6% alcohol. Analysis of the beer prepared by this method is in progress. Efforts are being made to prepare non alcoholic beverages in orange, lemon and mango flavors using sorghum malt extracts.

Papad and such other meal adjuncts: *Papad*, *Sandige*, *Murukku*, *Chakkuli* and such other products prepared normally at home or cottage industry level are important adjuncts in the Indian meal. Suitably blends flours from sorghum flour with other ingredients like legumes could be sheeted and cut into products of required shape and size, and toasted either in oil or hot air to prepare ready-to-eat multi-grain snack products. Low fat and high fibre snacks similar to tago chips from sorghum will find ready acceptance in country.

Parboiling or Hydrothermal treatment: Parboiling of hydrothermal treatment hardnes the endosperm texture and improves the decortication or milling and cooking characteristics of cereals. The process also enhances the retention of vitamins, minerals and some of the antioxidants of the cereals and upgrades their nutrients qualities.

Extrusion cooking and Roller drying: Among the various contemporary cereal processing technologies, extrusion cooking and roller drying are highly popular and are largely followed for corn and rice. It has been shown that, Sorghum could also be extrusion cooked to prepare ready with traditional spice and condiments. Alternately, the grits could be mixed with spice and condiments prior to extrusion to obtain RTE snacks of desirable taste and palate. This production being of ready-to-eat nature will have greater scope for use as weaning and supplementary foods and also as a component of edible films.

Jowar Pasta: All over the world, several ready to eat cereal products are being prepared for human consumption. These products enjoy wide popularity among consumers of all age groups. Sorghum pasta is prepared with sorghum semolina and maida. Lack of gluten content in sorghum requires minimum percentage of maida for texture maintaining in pasta technology.

Jowar Biscuits: Biscuits are popular ready-to-eat product consumed by different age groups in a family. Biscuit making is a conventional activity in many parts of the country. Despite the advent of modern, large capacity and automatic biscuit making plants, large section of people especially in semi-urban and rural areas still prefer fresh biscuits from local bakery as they are cheap and offer many varieties. Biscuits were assumed as sick- man's diet in earlier days. Now, it has become one of the most loved fast food products for every age group. Biscuits are easy to carry, tasty to eat, and reasonable at cost. Bakers and home scale industries use the traditional method of preparing biscuits which is completely done by hand.

Sorghum-Til Laddu: The major ingredients used in preparation of sorghum-till laddu are roasted sorghum flour, roasted til, roasted groundnut flour and milk powder. The roasted til and roasted groundnut are powdered and mixed with sorghum flour and milk powder. This was then mixed either with jiggery powder or sugar powder and pressed in a desired shape. This product is nutritionally good as til is a rich source of essential fatty acids and it is good for body metabolism. Groundnut is rich source of reservitol which is an anti-ageing factor.

Roasted flakes pedha: The major ingredient used for the preparation of roasted flakes pedha is the by-product extracted from the preparation of roasted flakes. The broken flakes were taken and thoroughly powdered and prepared in the form of pedha by using a little amount of jiggery syrup. This product is suitable for diabetic people as sorghum is a rich source of dietary fibre, iron and polysaccharides.

Bran pedha: The bran pedha is one of the value added by-products of bran extracted from milling of jowar. The bran is finely powdered and dried to remove the moisture content. Then it is mixed with skimmed milk powder, sugar and ghee. The mixture is then made into pedha and silver foil is pasted to make the pedha attractive and tasty.

1.10 Major problems associated with storage of grains

Storage losses: In India, post-harvest losses caused by the unscientific storage, insects, rodents, micro-organisms etc., account for about 10 per cent of total food grains (Anonymous, 1971). Reported storage losses vary widely between 5 - 50 % (Swaminathan 1977). The major economic loss caused by grain infesting insects is not always on account of the actual material they consume, but also on the amount contaminated by them and their excreta which makes food unfit for human consumption. Reduction of weight losses in bulk storage of grain and grain deterioration in storage is caused mainly through (a) bio-deterioration, (b) insects and pests, and (c) moulds and fungi. Bio-deterioration is due to the activity of enzymes present in the seed. According to one estimate, the harvest and post harvest losses of jowar is about 8.00 and 2.20 % at farmers' level during harvesting, threshing, winnowing, transportation and storage.

Estimated post-harvest losses of sorghum.

S. No.	**Losses** (during and other causes)	**Percentage** (of Losses)
1.	Threshing	1.0
2.	Transport	0.5
3.	Processing	-
4.	Rodents	2.50
5.	Birds	0.5
6.	Insect	3.0
7.	Moisture	0.5
	Total	8.00

(**Source:** Report of the Committee on Post Harvest Losses of Food grains In India, Ministry of Food and Agriculture, GOI, 1971.)

Estimated post- harvest losses of jowar at producers' level

S.No.	**Operations**	**Losses** (% to total production)
1.	Losses in transport from field to threshing floor	0.68
2.	Losses in threshing	0.65
3.	Losses in winnowing	0.32
4.	Losses in transport from Threshing floor to storage	0.21
5.	Losses in storage at farmers' level	0.34
	Total	**2.20**

(**Source:** Marketable Surplus and Post Harvest Losses of Jowar in India, 2002, Directorate of Marketing & Inspection, Nagpur.)

Conditions for infestation and damage for stored sorghum grains: Insect pests are a major problem in regions where the relative humidity is high, but temperature has the greatest influence on insect multiplication. At temperatures of about 32°C, the rate of multiplication is such that, a monthly compound increase of fifty times the original number is possible. Growth of insect pests and moulds raises both temperature and moisture, and thereby accelerates the activity of the enzymes, which would otherwise remain at a low level if conditions are favourable. Fungal attack in storage generally occurs where drying is inadequate, or where large numbers of insects are present, thereby causing a temperature rise in the grains, or where the stored crop is exposed to high humidity or actual wetting. All these circumstances lead to grain deterioration during storage resulting in weight loss, enhanced loss of nutrients and contamination with anti-nutritional factors. The qualitative changes in storage of these grains, especially at farm and home levels, are the main grey patches in our knowledge of post-harvest damages occurring in food grains. In assessing damage, emphasis is frequently on weight loss followed by kernel damage. Other forms of damage, such as reduction in quality and nutritive value, viability of seeds, microbial spoilage, and contamination with substances harmful to health are becoming non acceptable for edible purposes, which could be of greater importance than weight loss, are often ignored or given low priority.

Storage insects of sorghum: Storage pests are categorized into two types viz., primary and secondary storage pests based upon the type of material infested by them.

Primary storage pests: Insects that can damage sound, whole grains are called as Primary storage pests. (Eg: Rice weevil, lesser grain borer, Angoumois grain moth, Rice moth).

Secondary storage pest: Insects that damage broken or already damaged grains (Eg. Red flour beetle, Saw-toothed beetle etc.)

Storage pests of sorghum

Insect	Host range	Nature of damage
Primary pest		
Rice weevil: *Sitophilus oryzae,* Curculionidae, Coleoptera	Wheat, rice, maize, sorghum, paddy	Grubs and adults hollow out kernels and reduce it to mere powder leading to heating of grains.
Lesser grain borer: *Rhyzopertha dominica*, Bostrychidae, Coleoptera	Paddy, wheat, maize and sorghum	Heating is very common. Infestation is confined to a small area. Grubs and adults reduce the grain kernels to mere frass. Grubs eat their way into the grain or feed on the grain dust or starchy material.
Angoumois grain moth: *Sitotroga cerealella*, Gelechiidae, Lepidoptera	Paddy, maize, sorghum	It attacks both in fields and stores Grains are hollowed out by the larvae. Caterpillar enters the grain through crack or abrasion on grain. In bulk grain, infestation confines to one feet only.
Rice moth, *Corcyra cephalonica*	Maize, sorghum,Wheat	Larvae damage grains, adults are harmless. Grains are webbed.
Secondary pest		
Rust red flour beetle: *Tribolium castaneum*, Tenebrionidae, Coleoptera	Broken, grains, and milled products	Grubs feed on milled products. They feed on flour and other milled products. Heavy infestation causes stinking odour in flour affecting the dough quality.
Saw toothed grain beetle: *Oryzaephilus surinamensis*, Silvanidae, Coleoptera	Rice, wheat, sorghum, maize	Adults and grub cause roughening of grain surface. Grains with higher percentage of broken, dockage and foreign matter sustain heavy infestation, which leads to heating of grain.

Storage practices and grain damage: In India, traditional methods of grain storage are adopted. Open timber platforms are the main facilities used for temporary storage. The most common facilities for long-term storage were mud or clay silos, jute or polypropylene sacks, cribs made of plant materials exclusively, and clay jars and huts constructed of wood and straw, or earth bricks. Hermetic storage is practiced in Central India. Locals rely on indigenous pest management approaches.

Qualitative changes in storage of Sorghum and millets: Certain biochemical losses in jowar (*Sorghum bicolor* (L.) Moench.) grains due to infestation of weevil (*Sitophilus oryzae*) occur during storage. The total nitrogen, uric acid, and free fatty acid of grains increase considerably at the end of third and fourth month of storage. The non-reducing sugars, reducing sugars and total water soluble sugars decreased with the increase in insect infestation as compared to control. Moisture content and temperature of the grain showed increases with storage days in grain sorghum stored in the traditional underground storage pits in Eastern Ethiopia during 180 days of storage leading to deterioration in quality. The percentages of dry matter, crude protein, crude fat, starch and total carbohydrates for different storage days and percentage of ash showed significant differences. In the percentages of starch, differences in storage days and pits were less significant (Lemessa et al, 2000). It is generally known that insects often damage grain during storage, but little has been published on the effects of insect infestations on changes in grain odor during storage (Pederson, 1992; Pomeranz, 1992). According to Smith et al (1971), bread made from flour infested with *Tribolium* spp. or *Oryzaephilus surinamensis* (Lin.) exhibited undesirable taste. Quinone compounds were considered most responsible for the problem with *Tribolium* spp. The odor of grain infested with lesser grain borer has been described as "sweetish, musty" (Pederson 1992). Mites, which are often included with insects in discussions of stored grains and cereal products, have been investigated for odors and volatiles in infested grains (Tuma et al 1990).

Pest management approaches

Host plant resistance*:* Host plant resistance plays a major role in stored pest management. The factors viz., grain size, texture, seed coat, phenols, tannins played a major role in conferring resistance against insects.Thirty-five grain sorghum genotypes representing six variable groups (A/B-lines, R-lines, commercial varieties, germplasms, mutants and locals) were evaluated for the orientation, colonisation and oviposition responses of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), governing the antixenosis component of resistance. High degrees of antixenosis for colonisation by the adult weevils were observed among all the genotypes except 2077A and 2219B, which suggest a predominant reaction to gustatory rather than visual or olfactory stimuli. Greater levels of antixenosis for oviposition were noticed in 2077B, DJ 6514 and IS 11758 in free-choice tests, and 2219B, M 148-138, P 721 and Nizamabad (M) in no-choice tests. M 35-1, Swati and Lakadi showed greater susceptibility for oviposition. Significantly less damage to seed was observed on 2219A/B, 116B, IS 9487, IS 11758, CSV 8R M) and Local Yellow. The structural components and physical characteristics of sorghum kernels were studied as factors of resistance against the stored products pests *Sitotroga cerealella* and *Sitophilus oryzae*.. The kernels with glumes yielded less adult weevil progeny and sustained less kernel damage and weight loss from *S. oryzae*. Gelechiid emergence holes were located mainly in the crown end, and weevil holes mainly in the endosperm portion. The heavier and larger kernels produced heavier and larger adult progeny of both pests (Wongo,1990). Adults of *S. oryzae* died more quickly on the resistant cultivars than on the susceptible cultivars. The reduced longevity on the resistance cultivars was not due to lack of food or toxicity. A negative correlation was found between percentage weight loss and seed weight in the susceptible cultivar Ex-Mk, whereas there was no such relationship in the resistant cultivar FD1 (Adetunji, 1990).

Solar treatment*:* The most commonly adopted practice to get rid of storage insects is sun drying. Complete control of the adults of *T. castaneum* and *S. oryzae* was obtained at exposure periods of 60, 90 and 180 mins. Germination of the seeds was not affected at exposure periods of 60 and 90 s (94%), but exposure for 180 s resulted a slight decrease in germination to 82%. Conventional sun drying of seeds resulted in only 24.0 and 25.3% mortality of *T. castaneum* and *S. oryzae*, respectively, compared with 77.3 and 74.7% for the lowest exposure time of 30 s using solar heat treatment (Mohan et al, 1987). The damage by rice weevil was reduced in sorghum by harvesting grain at physiological maturity and artificial drying, solarizing the produce and storing in metal bins (Audilakshmi et al., 2005).

Botanicals*:* In the Indian context Neem has been used as grain protectant traditionally. However, among the botanicals, powders from sweet flag rhizome and custard apple (*Annona squamosa*) seed recorded the lowest seed damage, followed by powders from neem (*Azadirachta indica*) seed, neem leaf, Eucalyptus sp. leaf, *Clerodendron inermae* leaf and nochi (*Vitex negundo*) leaf. Minimum seed weight loss was observed in malathion and sweet flag rhizome treatments, which were significantly superior over all other treatments. Oils of Seasamum, castor and sunflower at 15ml/ kg of grain reduced oviposition of *T. granarium* and *S. granaries* (Sunil kumar *et al, 2005)*. All oils reduced egg hatchability at concentrations higher than 5 ml oil/kg seeds, with hatching percentage ranging from 47.9 to 60.5%, 31.6 to 52.2% and 32.8 to 53.8% for sesame, sunflower and castor oil, respectively. The oils at different concentrations had no significant effect on the germination of wheat and sorghum (Hassan, 2001). Japanese mint (*Mentha arvensis*) oil can be used effectively as a fumigant against *Sitophilus oryzae* in stored sorghum (Singh et al, 1995).

Chemicals*:* Amongst the present methods of insect control, chemical control is the most popular and perhaps most effective one. They may be used for both type of treatments prophylactic and curative treatment:-

- If the produce is meant for seed purpose, mixing 1 kg of activated kaolin per100 kg of seed and store/pack in gunny or polythene lined bags is suggested.
- Apply malathion 50 EC @ 10 ml/ litre of water and 3 litres of spray solution per 100 sq.m. (or) DDVP 76% SC : 7 ml per litre of water and 3 litres of spray solution per 100 sq.m.
- Air charge alleyways or gang ways with one of the following chemicals. Malathion 50 EC : 10 ml/litre of water (or) DDVP 76% SC: 7 ml/litre of water. Apply one litre of spray solution for every 270 cu.m. or 10,000 cu. feet. Spray the chemicals on the walls and floors and repeat the treatment based on the extent of flying and crawling insects.
- Gunny bag impregnation: Empty bags are soaked in 0.1% malathion emulsion for 10 minutes and dried before using for seed storage.
- Draw samples of seeds or grains at fortnightly intervals and classify the infestation as follows. When there is no pest - nil infestation. Up to 2 insects -mild infestation More than 2 insects - severe infestation. In case of severe infestation fumigate grains with Aluminium phosphide @ 3 tablets of 3 grams each per ton of grain for cover fumigation and for shed fumigation @ 21 tablets of 3 grams each for 28 cu. Metres. The period of fumigation is 5 days.

1.11 Researchable issues

Research priority decided by AICRIP, ICAR for 12th plan

- Development of high yielding kharif hybrids with 4.5-5.0 t/ha on-farm grain yield, with enhanced tolerance to grain molds and acceptable grain quality to meet the specific demands of user industries
- Increase productivity in rabi through development of high yielding varieties and

hybrids adapted under receding moisture condition with grain and stover quality and shoot fly resistance level better than that of M 35-1

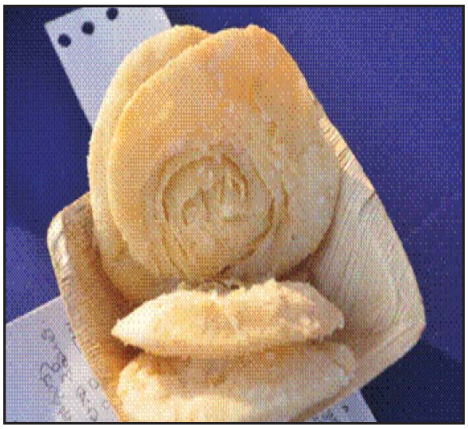
- Development of diverse bold seeded cytoplasmic male-sterile lines and R-lines with resistance against grain molds, shoot fly and other abiotic stresses
- Development of single and multi-cut forage hybrids and varieties having enhanced level of resistance against leaf diseases and greater fodder quality
- Development of high brix high biomas sorghum varieties and hybrids amenable to ethanol production
- Collection, evaluation, documentation, conservation and sharing local germplasm and elite genetic stocks
- Enhancement and diversification of genetic base of sorghum improvement programme through use of indigenous and exotic germplasm
- Enhanced profitability of kharif sorghum through management of grain mold resistance and promoting alternate uses for starch, syrup, alcohol, feed grain, etc.
- Improving water and nutrient-use efficiencies in rainfed and irrigated rabi production systems
- Development of profitable sorghum-based cropping systems to prevent area loss of sorghum
- Identifying/evolving elite and stable sources of resistance to biotic and abiotic stresses for use in breeding programmes
- Development of cost-effective integrated pest, disease and nutrient management strategies
- Breeder seed production with desired genetic purity
- Development of national database on sorghum research efforts, and promote technology exchange
- Technology popularization through front-line demonstrations and promoting linkages with extension agencies and user industries

Value added products of Sorghum (Jowar)


Cake


Wada


Biscuits


Sweet Puri


Roti


Laddu

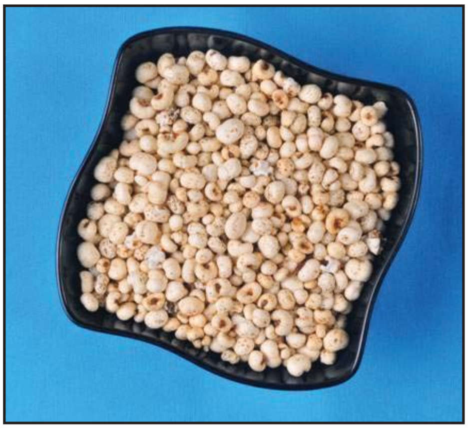

Pasta


Bread


Dosa


Lassi


Extruded


Puffs

Pearl millet
(Bajra)

2. PEARL MILLET (*Pennisetum glaucum* (L). R.Br.)

2.1 Introduction

The scientists believe that the primary centre of origin of Pearl millet is Africa from where it spread to India and other countries. Pearl millet (*Pennisetum typhoides*) hybridises spontaneously with elephant grass (*Pennisetum purpureum*) which is also of African origin and is believed that the two species may have had a common ancestor. Out of 32 species described by Stapf & Hubbard (1934) only two are known outside of Africa. In a study of the variability of a large number of strains of pearl millet from Africa and India, the highest range of variability was found in the strains from Africa. This is a further evidence of the African origin of the pearl millet.

Pearl millet (*Bajra*) is one of the major coarse grain cereals (millets) and is considered to be a poor man's food. It is widely grown in Africa and Asia since pre-historic times. It is grown in Africa where it replaced sorghum as the principle crop on sandy soils and in the dry areas. In Asia it is an important cereal crop of India, Pakistan, China and south eastern Asia. In India, it is the most important millet crop which flourishes well even under poor soils and adverse weather conditions. It provides staple food for the poor in a short period in the relatively dry tracts of the country. It is the most drought-tolerant crop amongst cereals and millets.

The grain of Pearl millet is superior in nutritive value than sorghum grains but inferior in feeding value. *Bajra* grains contain about 11.6% protein, 5% fat, 67.5% carbohydrates and about 2.3% minerals. Pearl millet (*Bajra*) grains are eaten cooked like rice or '*chapatis*' are prepared from bajra flour like flour of maize or sorghum. Pearl millet grain is also used as feed for poultry and green or dry fodder *(karbi)* for cattle.

Pearl millet occupies a unique position in rainy season (*kharif*), because of its drought hardy feature and staple food for millions of people. It also provides good quality fodder to cattle in the arid and semi-arid tropical regions and recognized as valuable forage crop because of its robust and fast growing habit. Its stalk is used for fuel and thatching.

In India, pearl millet is primary source of dietary energy (360 k cal/kg) for rural population in drier parts of the country and fourth most important cereal after rice, wheat and sorghum. It is a rich source of protein, calcium, phosphorous and iron. Pearl millet grain contains fairly high amount of thiamine, riboflavin and niacin. A significant portion of pearl millet grain is also used for non-food purpose such as poultry feed, cattle feed and alcohol extraction (Basavaraj et al., 2010).

Pearl millet, being a C_4 plant, has a very high photosynthetic efficiency and dry matter production capacity. It is usually grown under most adverse agro-climatic condtions where other crop fail to produce economic yields. In spite of this, Pearl Millet has a remarkable ablity to respond to favourable enviorments because of its short developmental stages and capacity for higher growth rates, thus making it excellent crop in short growing season under improved crop mangement.

Taxonomy: No good classification of pearl millet has been worked out by any scientist in spite of the fact that there is a wide range of variability in the cultivated strains. Stapf (1934) divided the genus *Pennisetum* into five sections: (a) *Pennicillaria*, (b) *Gymnothria*, (c) *Eupennisetum*, (d) *Heterostachy* and (e) *Brevivalvula*. The cultivated species *P. typhoides* S and H belong to the section *Pennicillaria* distinguished from the other by the conspicuous *Pennicillate* anthers. Thirty-two species belong to section *Pennicillate*.

The taxonomical classification presently adopted for pearl millet is based on Clayton 1972. However, de Wet (1977) accepted *Pennisetum glaucum* for annual pearl millet species instead of *P. americanum* suggested by Brunken (1977), present classification accepted is:-

Family	*Poaceae*
Subfamily	*Panicoideae*
Tribe	*Paniceae*
Subtribe	*Panicinae*
Section	*Panicillaria*
Genus	*Pennisetum*
Species	*glaucum*

Pennisetum is largest genera in the tribe *Paniceae* with five sections and approximately 140 species that are widely distributed in the tropics and subtropics (Clayton, 1972). It is placed close to the genus *Cenchrus* (Stapf and Hubbards, 1934 and Bor, 1960) on the basis of spikelets that are arranged in groups surrounded by involucre. Inter-generic hybrids between pearl millet *and Cenchrusciliaris* L. have also been reported (Read and Bashaw, 1974).

According to Brunken (1977), *Pennisetum* includes two reproductively isolated species viz. *P purpurium* Schumach, a tetrapolid (2n = 28) perennial species which occurs throughout the wet tropics of the world; and *P. americanum* (syn. *P. glaucum*) (L) Leeke, a diploid annual species, native to the semi-arid tropics of Africa and India. *P. glaucum (P. americanum* according to Brunken 1977) contains three sub species:

a) Sub-sp: *glaucum*- cultivated, involucres persistent at maturity, distinctly stalked.

b) Plants wild or weedy, involucres readily deciduous at maturity, short stalked or sub-sessile.

    i. Sub-sp. *violaceum (monodii)* - Involucres sub-sessile, stalks less than 0.25 mm long; mature grains 0.6-1.0 mm deep. Considered to be wild progenitor of cultivated pearl millets.

    ii. Sub sp. *stenostachyum* – Involucre short stalked; stalk more than 0.25 mm long, mature grain 1.0-2.0 mm deep.

Pennisetum glaucum sub sp. *glaucum* is the only cultivated species for seed purposes. *P. purpurium* and its hybrids with bajra in both directions (bajra x napier and napier x bajra) are cultivated for fodder purposes in some areas of world and India.

Morphology: Pearl millet (*Pennisetum typhoides*) belongs to Gramineae family. It is tall, tillering annual plant which usually grows to a height of one meter to over three metre. The botanical description of main parts of *Bajra* plant in given below:

Root System: The root system of Pearl millet is fibrous like that of most grasses. At the time of germination, a primary root develops from seed and penetrates deep in the soil. Primary root consists of several thin and fine lateral roots. When seedling reaches two to three leaf stages, the secondary roots develop from the bud located on lower-most node near soil surface. Some of the roots arise from second and third nodes above the soil surface. Their primary function is to give anchorage to the plants. These roots are known as 'brace' or 'Prop' roots. Tillers arise from the basal nodes.

Stem: The stem is solid and usually single, but often there are branches, both primary and secondary. It is made up of nodes and internodes. The nodes are slightly swollen, while internodes are cylindrical and glabrous. The stem is about 2.5 cm in thickness. The length of the inter-node increases from the bases of the culm upwards. The lower internodes are completely covered with leaf sheath while upper ones are partially covered. A shallow groove is found above each node. The auxiliary bud is located in this groove. There is no bud on the uppermost node, but it gives rise to floral stalk buds in the groove of nodes give rise to leaves.

Leaves: Leaves of Pearl millet are long fairly broad and held erect by thick midribs. Leaves arise alternately on stem. They are smooth on the lower surface and rough on the upper surface. Leaves consist of a blade and a sheath. The base of the blade is slightly auricled; the ligule is short (4-5 mm) and membranous with a fringe of hairs. The blade is flat, lanceolate, long pointed and possesses numerous hairs on both surfaces. A thin translucent portion called leaf junction connects the leaf blade with sheath. The leaf sheath is open, a little thicker than the blade and encircles the stem almost completely. The leaf margins, like those of sorghum, bear small saw-like teeth. Stomata are equally distributed on both the surface.

Inflorescence: The inflorescence of Pearl millet is almost a cylindrical spike densely packed with the spikelets. The number of spikelets may be from 800 to 3000 per spike. The length of the spike may vary from 15 to over 60 cm. Spikelets usually occur in pair. Each spikelet consists of two glumes and two flowers, the lower flower being usually male and the upper hermaphrodite or perfect. The perfect flower is the first to appear. It has a lemma, thin palea, three stamens with characteristic pennicillate anthers and a carpel with two styles.

Two to three days after the emergence of the inflorescence, the bluish-white styles begin to protrude out of the glumes. The stigmas remain receptive for one to two days to receive pollen from other plants for fertilization. The anthers begin to emerge after the styles have started to dry up. By the time the anther emergence starts, the whole panicle will complete the emergence of the styles and stigmas. Due to protogynous nature of the inflorescence usually cross pollination takes place in pearl millet.

Caryopsis (Grains): The seed or caryopsis is almost oval with one of its ends tapering. The seed is 3-4 mm long and 2-2.5 mm wide. The colour of grain varies from whitish-yellow to grey or dull light blue, while the embryo has a reddish tinge. The embryo is small and located at the tapering end of the grain.

2.2 Comparative analysis

India is the largest producer of this crop, both in terms of area (9.12 million ha) and average production of 9.2 million tonnes during 2007-08 to 2011-12 with average productivity of 1009 kg/ha. As compared to the early 1980s, pearl millet area in India declined by 25% during 2011-12, but production increased by 22% owing to 50% increase in productivity. The major pearl millet growing states in India with their production, productivity and area are given in **Table-15**. The productivity of pearl millet of summer is higher than kharif due to better management, assured irrigation and good quality seed of varieties/hybrids by the farmers and pest incidence during summer session.

Table-15: State/season specific distribution of Pearl millet in India (2007-08 to 2011-12).

State	Area (Lakh ha)% to All India			Production (Lakh tonnes) % to All India			Yield (kg/ha)		
	Kharif	*Rabi/* Summer	Total	*Kharif*	*Rabi/* Summer	Total	*Kharif*	*Rabi/* Summer	Total
Rajasthan	51.86 (58.09)	-	51.86 (56.85)	39.40 (45.58)	-	39.40 (42.82)	760	-	760
Maharashtra	10.11 (11.32)	-	10.11 (11.08)	9.00 (10.41)	-	9.00 (9.78)	890	-	890
Uttar Pradesh	8.72 (9.77)	-	8.72 (9.56)	14.44 (16.70)	-	14.44 (15.69)	1656	-	1656
Gujarat	6.22 (6.97)	1.85 (94.39)	8.07 (8.85)	5.37 (6.21)	5.47 (98.20)	10.84 (11.78)	862	2956	1342
Haryana	6.13 (6.87)	-	6.13 (6.72)	11.07 (12.81)	-	11.07 (12.03)	1807	-	1807
Karnataka	3.19 (3.57)	0.01 (0.51)	3.20 (3.51)	2.60 (3.01)	0.01 (0.18)	2.61 (2.84)	817	1200	819
Madhya Pradesh	1.72 (1.93)	-	1.72 (1.89)	2.78 (3.22)	-	2.78 (3.02)	1616	-	1616
Andhra Pradesh	0.48 (0.54)	0.10 (5.10)	0.58 (0.64)	0.64 (0.74)	0.09 (1.62)	0.73 (0.79)	1338	922	1264
Tamil Nadu	0.53 (0.59)	-	0.53 (0.58)	0.89 (1.03)	-	0.89 (0.96)	1663	-	1663
J & K	0.18 (0.20)	-	0.18 (0.20)	0.11 (0.13)	-	0.11 (0.12)	601	-	601
Others	0.14 (0.16)	-	0.14 (0.15)	0.15 (0.17)	-	0.15 (0.16)	1079	-	1079
All India	**89.27 (100)**	**1.96 (100)**	**91.23 (100)**	**86.45 (100)**	**5.57 (100)**	**92.02 (100)**	**968**	**2842**	**1009**

Source: Directorate of Economics & Statistics, GOI.
NB: Values in parenthesis are % to All India.

Pearl millet accounts for about 50% of the total area under all millets in the world. Pearl millet is ranked third after rice and wheat in acreage. Pearl millet (*Pennisetum glaucum* (L). R. Br.) is cultivated on about 30 M ha in more than 30 countries of five continents viz. Asia, Africa, North America and Australia. Pearl millet is cultivated mostly in Africa (about 14 million ha) and Asia (about 12 million ha). Sixty percent of world millet area is in Africa. Asian countries occupy 35% of world millet area. European countries cover 4% of millet area and 1% is in North America. The developing countries in Asia and Africa contribute about 93% of total millet production in the world. Asia alone contributes 43% of world millet production; European countries produce 6% and North America produces approximately 1%. Country-wise mean (2007-2011) area, production and yield of millets (excluding sorghum) is given at **Table-16**.

Table-16: Mean area, production and yield of Millets (excluding sorghum) (2007-2011)

S.No.	Country	Area (Million ha)	Production (Million tonnes)	Yield (Kg/ha)
1	Angola	0.2 (0.6)	0.1 (0.3)	324
2	Burkina Faso	1.3 (3.7)	1.0 (3.2)	793
3	Cameroon	0.1 (0.3)	0.1 (0.3)	1328
4	Chad	1.0 (2.9)	0.6 (1.9)	584
5	China	0.8 (2.3)	1.4 (4.5)	1736
6	Côte d'Ivoire	0.1 (0.3)	0.0	761
7	Democratic Rep. of the Congo	0.1 (0.3)	0.0	677
8	Eritrea	0.1 (0.3)	0.0	379
9	Ethiopia	0.4 (1.1)	0.5 (1.6)	1327
10	Gambia	0.1 (0.3)	0.1 (0.3)	930
11	Ghana	0.2 (0.6)	0.2 (0.6)	1077
12	Guinea	0.3 (0.9)	0.3 (1.0)	839
13	India	11.2(32.2)	11.8 (37.9)	1050
14	Kenya	0.1 (0.3)	0.1 (0.3)	684
15	Mali	1.7 (4.9)	1.4 (4.5)	808
16	Mozambique	0.1 (0.3)	0.0	466
17	Myanmar	0.2 (0.6)	0.2 (0.6)	914
18	Namibia	0.2 (0.6)	0.0	160
19	Nepal	0.3 (0.9)	0.3 (1.0)	1102
20	Niger	6.7 (19.3)	3.2 (10.3)	467
21	Nigeria	4.2 (12.1)	5.7 (18.3)	1358
22	Pakistan	0.5 (1.4)	0.3 (1.0)	622
23	Russian Federation	0.4 (1.1)	0.5 (1.6)	1229
24	Senegal	0.9 (2.6)	0.6 (1.9)	699
25	Sudan (former)	1.8 (5.2)	0.5 (1.6)	290
26	Togo	0.1 (0.3)	0.0	684
27	Uganda	0.5 (1.4)	0.8 (2.6)	1846
28	Ukraine	0.1 (0.3)	0.2 (0.6)	1455
29	United Republic of Tanzania	0.3 (0.9)	0.3 (1.0)	803
30	United States of America	0.2 (0.6)	0.3 (1.0)	1759
31	Yemen	0.1 (0.3)	0.1 (0.3)	752
32	Zimbabwe	0.2 (0.6)	0.0	154
	World	**34.8**	**31.1**	**895**

NB : Figures in parenthesis indicate % share to World total.
Source : FAO Year Book, 2013

At individual country level, India has the largest area (>9 millon ha) with 9.2 million tonnes of production. Pearl millet is ranked third after rice and wheat and is grown in Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, Haryana, Tamil Nadu, Andhra Pradesh and Karnataka, though first five states account for >90% of area in pearl millet.

Most of pearl millet in India is grown in rainy (kharif) season (June-September) but is also cultivated during summer (February-May) in Gujarat, Rajasthan and Uttar Pradesh and during post-rainy (rabi) season (November-February) at a small scale in Maharashtra and Gujarat (Mula *et al.*, 2009). During kharif season, pearl millet is largely grown as rainfed crop except in some areas in eastern Rajasthan, southern Haryana and western Uttar Pradesh where supplemental irrigation is provided incase of shortage of rainfall during the crop season. In summer season pearl millet is cultivated as an irrigated crop under high levels of agronomic management.

2.3 Varietals development

The pearl millet has recorded an increase in productivity continuously for last 25 years resisting the effect of rise in temperature and other climatic changes; hence it can be treated as one of the most resilient crop to changing climate. This also proves that it has sufficient genetic resources to adapt to rise in temperature in future.

Yields more than 50 quintal/ha have been recorded in front line demonstrations (FLDs) and 70 and 80 q/ha were achieved in National demonstration with good management practices at Mandor (**Table- 17**).

Table-17: Detail of FLD conducted since 1997 by All India Coordinated Pearl Millet Improvement Project (AICPMIP).

Year	Rajasthan			Gujarat			Haryana		
	Area (ha)	Yield (Kg/ha)		Area (ha)	Yield (Kg/ha)		Area (ha)	Yield (Kg/ha)	
		IP	FP		IP	FP		IP	FP
2011	80	1794	1366	15	1793	1540	41.6	2980	2570
2010	123	1696	1369	25	2033	1769	55.6	2303	2400
2009	43	1790	1285	12	2202	1914	47.2	2500	2000
2008	-	-	-	50	3080	2578	101	2559	2246
2007	187.9	1065	918	174	1545	1223	72.6	2579	2109
2006	13	737	450	35	2420	2000	-	-	-
2005	-	-	-	40	2651	2328	-	-	-
2004	185.5	1526	1146	114.8	-	-	42	1842	1634
2003	569.7	1580	1126	158	2160	1709	83.2	2060	1728
2002	-	-	-	42	2243	1969	-	-	-
2001	49.3	1370	907	15.6	2663	2259	39	2287	1903
2000	74	1357	1134	24	2291	2011	15	2551	2223
1999	45	1577	1077	10	2259	2041	10	2075	1725
1998	52	1727	1007	9	3343	2438	23	2431	1840
1997	27	1507	1074	-	-	-	22	2040	1615

Table-17 contd….

Year	Tamil Nadu			Karnataka			MP		
	Area (ha)	Yield (Kg/ha)		Area (ha)	Yield (Kg/ha)		Area (ha)	Yield (Kg/ha)	
		IP	FP		IP	FP		IP	FP
2011	-	-	-	12	1565	1370	12	3095	2340
2010	15	2179	1638	11	1196	1063	-	-	-
2009	25	2128	1737	-	-	-	25	2128	1737
2008	-	-	-	-	-	-	-		-
2007	-	-	-	-	-	-	27	2265	1916
2006	-	-	-	-	-	-	175	2159	1605
2005	40	2224	1677	-	-	-	-	-	-
2004	10.6	1966	847	15	1333	867	15	2556	1731
2003	2	1980	1329	28.4	1852	1647	31	3105	2345
2002	10	1828	1622	-	-	-	-	-	-
2001	5	3850	1424	3.5	2142		10	1317	1043
2000	10	4558	3860	10	2160	1219	-	-	-
1999	10	4508	2673	10	2054	1570	5	2088	1544
1998	-	-	-	18	2004	1461	11	2507	2015
1997	10	1236	811	12	1755	1171	11	1625	1191

Table-17 contd….

Year	Maharashtra			Utter Pradesh		
	Area (ha)	Yield (Kg/ha)		Area (ha)	Yield (Kg/ha)	
		IP	FP		IP	FP
2011	32.8	1980	1581	25	2349	-
2010	20	2452	2122	25	1926	-
2009	10	2174	1871	15	3372	1564
2008	-	-	-	-	-	-
2007	125	1847	1730	40	3230	2280
2006	30	2330	1980	-	-	-
2005	-	-	-	-	-	-
2004	110	2147	1726	-	-	-
2003	199	-	-	65.6	2988	1420
2002	-	-	-	-	-	-
2001	40	1864	1511	10	2617	2031
2000	29	1300	1019	10	1839	1590
1999	20	2055	1475	10	1980	1583
1998	8	2237	1913	11	2308	1904
1997	17	1202	827	-	-	-

IP- Improved practices.
FP- Farmer practices.

FLD maximum minimum yields reported (Quintal/ha)

		2009		2010		2011	
		max	min	max	min	max	min
Haryana	Kharif	38	22	36.6	10	42	15
Gujarat	Kharif	26	18	26	15	24	13.7
	Summer	-	-	-	-	55	31
Maharashtra	Kharif	29.3	10.6	32.1	11.3	25	9.78
	Summer	-		39	10.4	-	-
Tamil Nadu	-	27.5	18.1	-	-	28.5	14
MP	-	24	16	32	19.5	36	25.4
Rajasthan	Kharif	31.9	-	41	12.5	27	16
Punjab	Kharif	42	20.4	-	-	-	-
UP	Kharif	-	-	28	9.5	27.5	
Karnataka	Kharif	-	-	15	6.8	25.5	12.2

Maximum productivity recorded in National demonstration on pearl millet at Mandor, Jodhpur following full package of practices

S. No.	Year	Hybrid	Grain yield (Q/ha)
1.	2011	P-9444	79.98
2.	2012	VBBH 3115	69.84

Adoption of hybrids and high yielding varieties and their impact

High yielding varieties, hybrids and open-pollinated varieties (OPVs) have been widely adopted by Indian farmers. Currently, nearly 65% of pearl millet area is under improved cultivars, mainly hybrids. Following the adoption of high yielding varieties and disease resistant cultivars, pearl millet productivity has gone up from 539 kg/ha during 1986-90 to 1009 kg/ha during 2007-11 registering 73% improvement, which is highest among all food crops. The rate of improvement in pearl millet productivity during 1986-2010 has been 20 kg/ha/year as compared to 6.3 kg/ha/year during 1960-85. This extent of improvement in pearl millet productivity has resulted in more than 45% improvement in its grain production, from 5.83 million tons during 1986-90 to 8.48 million tons during 2006-10.

2.4 Climatic requirement

Pearl millet is a rapid-growing and warm weather crop suitable for areas with 40 to 75 cm of annual rainfall. It has high degree of resistance for drought conditions. During the vegetative growth of the crop, moist weather is useful. The rainfall at flowering time is harmful as it washes off pollen and consequently there is poor seed setting. The crop does best under conditions of light showers followed by bright sunshine. Usually, pearl millet is grow in those areas where it is not possible to grown sorghum because of high temperatures and low rainfall. Pearl millet is grown as a *Kharif* crop in northern India but with irrigation it can be grown as a summer crop in Tamil Nadu, Karnataka and Punjab. The best temperature for the growth of Bajra is between 20 to 28 °C.

Pearl millet is most commonly cultivated under rainfed conditions (>92%) in the arid and semi-arid regions of country where annual rainfall ranges from 150 to 750 mm, most of which is received during June to September (Harinarayana *et al.*, 1999). Because of its cultivation largely in rainfed production systems, pearl millet growth is constrained several abiotic stress. Drought is the primary abiotic constraint and is caused by low and erratic distribution of rainfall. The coefficient of variation of annual rainfall ranges from 20 to 30% leading to variable drought conditions within and between crop seasons. Hence, development of pearl millet cultivars suitable for rain fed and unpredictable low-rainfall situations has been priority area in crop improvement.

The maximum air temperature around 43 °C is common in the beginning of rainy season. Formation of crust is also common in soil with high silt contents. Both of these factors lead to poor plant stand. Hence cultural interventions have been explored to get improved emergence and adequate plant stand. Crop geometry, weed control and water management to optimize crop yields in drought prone environment have also been worked out.

Soil in the regions where pearl millet is cultivated is often infertile as they contain low amount of organic matter (0.05-0.40%) because of low vegetation cover, coarse soil texture and prevailing high temperature (Kumar *et al.*, 2009). Soils also contain low-to-medium levels of available phosphorous (10-25 kg/ha). Organic fertilizers are rarely applied resulting in extremely nutrient depleted soils for pearl millet. Therefore, research on nutrient management has been a critical component of coordinated research in order to increase and stabilize the crop productivity.

Pearl millet is also grown with supplemental irrigation with high input and management condition in small pockets scattered throughout the pearl millet growing regions. The environmental resources in such pockets are sufficient enough to support high levels of productivity to obtain a maximum return for the input supplied. Hence, maximization of yield under high crop management is also an important research priority in the coordinated programme.

Pearl millet is becoming an important crop during summer season (February to May) in Gujarat, Rajasthan and some parts of Uttar Pradesh where it is grown under high input and management conditions. High temperature, often more than 42 °C, persists during flowering and grain-filling stage of the crop in parts of western India. Tolerance to high temperature is, therefore, becoming an important research area in the coordinated research programme.

Phases of Plant growth

The growth and development of pearl millet can be divided into three major phases (**Table-18**):-

Growth phase-1: The seedling establishment with root, leaf and tiller development takes place during this phase. Panicle initiation also begins.

Growth phase-2: Elongation of all the leaves, emergence of all tillers, floral initiation in tillers, and stem elongation take place during this phase. The elongation of the panicle and formation of floral parts are found in this phase. This phase ends with the emergence of stigmas on the panicle.

Growth phase-3: This phase begins with the fertilization of florets and continues up to maturity of the plant. The dry matter accumulation is mainly in grain formation and partly in the enlargement of stem and leaves of the tillers. The end of this phase is physiological maturity, indicated by the development of dark layer at the bottom of the grain.

Table-18: Time taken to attain different growth stages in short duration and long duration cultivars.

Growth stage	Character	Approximate days after emergence	
		Short duration	Long duration
Phase 1			
0	Coleoptile emergence	0	0
1	3rd leaf stage	6	6
2	5th leaf stage	14	15
3	Panicle initiation	22	28
Phase 2			
4	Flag leaf visible	33	43
5	Boot stage	36	47
6	50% stigma emergence	40	50
Phase 3			
7	Milk stage	49	59
8	Dough stage	58	68
9	Physiological maturity	70	80

2.5 Genetic potentiality advancement

Given a wide range of environmental conditions under which pearl millet is grown in India and considering requirements for local adaptation, the whole pearl millet area has been divided into three zones viz., A_1, A and B Zone.

- ✓ A_1 Zone: is composed of parts of Rajasthan, Gujarat and Haryana receiving less than 400 mm annual rainfall. This zone is highly drought-prone and has light sandy soils and high temperatures.
- ✓ Zone A: is composed of the remaining parts of the states of Rajasthan, Gujarat and Haryana and the entire pearl millet growing areas of other northern states like Uttar Pradesh, Northern Madhya Pradesh, Punjab and Delhi. This zone has sandy loam soils and an annual rainfall of greater than 400 mm. Irrigation facilities are also available in some areas.
- ✓ Zone B: is comprised of the southern state of Maharashtra, Karnataka, Tamil Nadu and Andhra Pradesh with rainfall greater than 400 mm, heavy soils and mild temperature conditions. The B zone has shorter days compared to A_1 and A zones.

Multi-location testing of new experimental open-pollinated varieties (OPVs) and hybrids (hereafter referred to as cultivars) is carried out through coordinated trials of AICPMIP each year conducted at site located in different agro-climatic zones of the country. These trials are conducted at AICPMIP research centers and cooperating centers of both public and private sectors.

Initial Trials are categorized in three groups on the basis of maturity. Early trial, consisting of test entries maturing in <75 days, are conducted in A zone; and trials with entries >85 days duration, are conducted in B zone. The performance of test entries is compared with three checks. First of them is the 'national check' which is the hybrid/variety that is widely grown and has established its superiority over time and space. Second check is called as 'local check' which is a popular variety in a region/zone. The third check termed as 'best check' is the hybrid/variety that has been released and notified most recently.

The test cultivars found promising for grain and stover yields are promoted to the Advance Trials that are conducted on zone basis. Additional data are generated on the performance of test entries with respect to their response to different doses of fertilizers and planting dates in second year of Advance Trials which is the third and final year of evaluation.

Average number of entries tested each year in coordinated trials during 1986-2010 is given in **Table-19**. The test cultivars have increased substantially during the period. The number of hybrids tested annually has gone up by 69%, from 77 to 130, while number of OPVs tested each year has come down from 32 to 17. This resulted in an overall increase of 35% in number of experimental cultivars tested in different zone of the country. It is thus evident that AICPMIP has a very strong research/development and testing network for field evaluation of pearl millet hybrids and OPVs.

Table-19: Average number of experimental cultivars evaluated each year in coordinated trials during 1986-2010.

Period	Average number of cultivars tested each year		
	Hybrids	OPVs	Total
1986-1990	77	32	109
1991-1995	100	35	135
1996-2000	85	27	112
2001-2005	121	21	142
2006-2010	130	17	147

Apart from grain and stover yields, major emphasis during coordinated testing is placed on downy mildew incidence. Test entries showing more than 10% of downy mildew incidence on susceptible check 7042S are rejected from first year onwards. Three years of testing for downy mildew resistance minimize the risk of releasing susceptible hybrid and OPV. Normally it takes three year of testing to identify a promising hybrid/variety. The average performance over three years of testing in a particular zone or across zone is taken into consideration for proposing a cultivar for release.

Breeding objectives

High grain yield combined with maturity duration, mostly in the range of 75-85 days, as per the agro-ecological requirements was accorded highest priority in the cultivar development programme. Due to the growing importance of pearl millet stover for fodder purpose, there has been considerable emphasis in recent times on breeding for high stover yield in combination with high grain yield. Apart from the evident quality traits both in the grain (size, shape and color) and stover (less rust, thinner stem, lodging resistance) that receive some attention, consideration of any other quality traits in cultivar breeding has been negligible. In case of diseases, the highest priority has been given to breed for downy mildew resistance. Recently, blast disease has increased significantly in all the pearl millet growing regions; hence resistance breeding for blast disease has also gained the priority. Drought tolerance breeding so far has remained largely a strategic research issue. Drought escape mechanism has been exploited mostly by targeting early maturity and this approach has been very effective for drought prone north-western India.

Improving Male Sterile (A) lines

In the breeding of seed parents (A-lines), high grain yield potential of A-lines, both as lines *per se* as well as in hybrids (i.e. combining ability), is the most important consideration. Thus high yield potential is the first target trait for which selection is made visually in un-replicated nurseries. High yield, however, is achieved in combination with other agronomic and farmer preferred traits. Some of the traits in hybrids common to all the environments include lodging resistance, compact panicles, good exertion, and seed set. Traits that have regional preferences include different maturity durations, plant height (grain vs. dual-purpose), tillering ability, seed color and seed size. Most of these agronomic traits have high heritability for which visual selection during generation advance is fairly effective. These traits of the parental lines are expressed in hybrids to varying levels, depending on the corresponding traits in the pollen parents. The A-lines must also have complete and stable male sterility and B-lines must have profuse pollen production ability across the seasons and sites.

The d_2 dwarf plant height has emerged as the most dominant plant type concept in seed parent breeding. This has several operational advantages: (i) it provides the option for breeding hybrids of varying heights, (ii) it provides greater control on seed yield and quality by reducing the risk of lodging that can occur under high management seed production conditions and (iii) it allows a much rapid detection and efficient rouging of the off-types and pollen shedders in A lines. A large number of designated A lines bred at AICPMIP centre and ICRISAT represent considerable morphological diversity for the agronomic traits. In view of the increasingly important role of the stover, seed parent development programme is targeting medium late maturity duration. New plant types such as lines with long panicles (30-80 cm compared to standard normal of 10-20 cm), thick panicles (40-50 mm diameter compared normal 20-30 mm) and large seed size (17-20 g of 1000-seed mass compared to standard normal of 9-12 g) are being developed at ICRISAT and many AICPMIP centres.

Selection for downy mildew resistance has been a top priority in hybrid parental line development. Evaluation of progenies for downy mildew resistance during the course of inbreeding and selection runs concurrent to agronomic evaluation to ensure that B and R-lines finally produced are resistant to this disease. Trait specific breeding lines are evaluated for downy mildew resistance against pathotypes from the region for which the lines are targeted. However, breeding lines in some trait-specific groups (e.g. early maturity, medium seed size, and average tillering with long panicles) are evaluated in successive steps against more than one diverse pathotypes because of the wider requirement of such materials.

Restorer (R) lines

Restorer lines must produce profuse pollen that should remain viable at air temperatures as high as 42-44 ^{o}C. Also pollen parents must produce highly fertile hybrids, which confers some degree of protection from ergot and smut infection. Besides being able to produce high yielding hybrids, the restorers should also be highly productive which is important from the viewpoint of seed production economy. It is desirable to breed pollinators of 150-180 cm height, but no shorter than the A line with built in attributes of panicle, maturity and tillering that will be preferred by farmers in the hybrids. Pollinators must have acceptable level of lodging resistance and should also possess adequate levels of resistance to various diseases.

Diversification of Cytoplasmic Male Sterility (CMS) system

Large-scale use of the single A_1 CMS source during the 1960s in all the hybrids had raised a concern regarding its potential vulnerability to diseases and insect-pests. As a result, continuing efforts were made to search for alternative CMS sources. This led to identification of A_2 and A_3 CMS sources from *P. glaucum* sub-species *monodii (=violaceum)* accessions (Marchais and Pernes, 1985; Hanna, 1989); and A_{egp} and A_5 CMS sources from gene pools (Sujata et al., 1994; Rai, 1995). Based on the differential male-fertility restoration patterns of hybrids using common restorers, it has been established that the A_1, A_2, A_3, A_V, A_4 and A_5 were distinctly different CMS systems. However, the A_1 cytoplasm based CMS lines are extensively used in developing pearl millet hybrids in India.

Commercial viability of a CMS system for seed parent development depend on the stability of male-sterility, frequency of maintainers in a wide range of breeding materials, nature of character association and inheritance of male-sterility, all of which influence seed parents breeding efficiency. A large number of inbred lines with good combining ability and having recessive allele for the gene responsible for restoration of fertility, are converted into new CMS lines mostly with A_1cytoplasm, through repeated back crossing.

Diversification of restorers

So far, almost entire emphasis in restorer breeding has been on the utilization of the A_1 CMS system. Hence, excellent restorers of this CMS system are abundantly available. But there is a serious lack of the A_4 restorers and A_5 restorers in elite agronomic genotypes. However, excellent genetic stocks of A_4 and A_5 restorers developed at ICRISAT, are being used in backcross breeding for development of restorer lines of A_4 and A_5 CMS systems. An efficient backcross breeding method for converting elite inbred lines into their A_4 and A_5 restorer versions has been developed. Also, moderate and low frequency of restorers of the A_4 and A_5 CMS systems, respectively have been found in most of the populations surveyed. Their frequency in these populations can be rapidly increased by recurrent selection as shown for the A_1 system restorers.

Molecular Breeding

Genetic linkage map

Efforts towards molecular breeding started in pearl millet in early 1990s with the development of a molecular marker-based genetic linkage map which largely comprised of RFLP loci (Liu *et al.*, 1994). This linkage map was short (circa 300 cM), but it has now been expanded (Qi *et al.*, 2004) and current genetic linkage map of pearl millet covers 1148 cM (Supriya et al., 2011) and SNP markers have also been included (Bertin et al., 2005; Sehgal *et al.*, 2012). The most recently published, well-saturated genetic linkage map of pearl millet provides coverage with 321 marker loci (258 DArTs and 63 SSRs) distributed over 1148 CM (Supriya *et al.*, 2011). Further, a consensus map based on SSR and DArT markers mapped across four pearl millet recombinant inbred line (RIL) mapping populations is now under developed at ICRISAT.

Quantitative trait loci (QTL) mapping and marker assisted selection

Initial map was followed by identification of QTLs using several different mapping populations. The target traits for pearl millet QTL mapping have been downy mildew resistance, grain and stover yield under favourable conditions, stover quality and iron and zinc concentration in pearl millet grain.

Downy mildew resistance

Several putative QTL have been identified that determine a significant proportion of downy mildew resistance in pearl millet (Hash *et al.*, 1997). Downy mildew resistant version of an early-maturing hybrid HHB 67 has been released as "HHB 67 Improved" for drought-prone areas in the states of Rajasthan, Haryana and Gujarat. The parental lines of the original hybrid were improved for downy mildew resistance through marker-assisted as well as conventional backcross breeding programmes. The gene for downy mildew resistance was added to the male parent, H 77/833-2, through marker-assisted breeding using elite parent ICMP 451 as the resistance gene donor. The gene for downy mildew resistance to the female parent, 843A/B was transferred from DM resistant source ICML 22 through conventional backcross breeding, proved to be more effective than any of the single QTL introgression from ICMP 8540 or P7-3. Therefore, after initial hybrid testing with a wide range of improved versions of 843A/B (Khairwal *et al.* 2006), hybrids based on seed parent pair ICMA/B 99022 (conventional backcross derivative of 843A/B) and two improved pollinators (ICMR 01004 and ICMR 01007) bred by marker-assisted backcrossing, were selected for further evaluation, leading to the release of HHB 67 Improved (Hash *et al.* 2006a). Comparison of downy mildew reactions of the donor (ICMP 451-P6 and ICML 22) and recurrent (H77/833-2 and 843B) parents; and selected backcrossing products (e.g. ICMB 99022, ICMR 01004 and ICMR 01007) included in a larger set of materials screened across 9 diverse virulent downy mildew pathogen isolates from India, suggested that resistance pyramiding conferred border spectrum of resistance than expected based on performance of parents involved (Hash *et al.*, 2006b)

Several additional downy mildew resistance QTLs have been validated by integrated marker-guided backcross transfer (i.e. backcrossing with integrated conventional and marker-assisted selection) to elite seed parent (ICMB 841 and ICMB 93333) and/or pollinator (J 2340 and ICMR 01004) backgrounds. To date, while many pearl millet downy mildew resistance QTLs have been mapped, essentially all confer pathogen population specific partial resistance of the sort expected from defeated major resistance genes. Only rarely has screening of a particular mapping population against a particular downy mildew isolate revealed the predominant role of an effective single major resistance gene. Therefore, the most promising approach for breeding downy mildew resistance that is both stable (across sites) and durable (across years), appears to be one based on pyramiding of QTLs for incomplete resistance from diverse sources in both sides of the hybrid parentage (preferably different effective resistances in seed parent and pollinator). It is further recommended that host plant resistance deployed in genetically uniform hybrids be backstopped with appropriate management practices (crop and cultivar rotation, and use of appropriate prophylactic fungicidal seed dressings) to extend the useful economic life of this resistance (Hash *et al.*, 1997; Witcombe and Hash, 2000; Hash *et al.*, 1999; Hash and Witcombe, 2002).

Drought tolerance

Because of intrinsic difficulties in breeding for drought adaptation by conventional breeding (Barker *et al.*, 2005; Blum, 1988), this field has become a prime focus for molecular marker-assisted breeding. Genetic mapping for drought tolerance has targeted terminal drought. Several major QTLs have been identified that have significant effects on pearl millet yield in drought stress environments (Bidinger *et al.*, 2005; Yadav *et al.*, 2002; Yadav *et al.*, 2004). Comparison of hybrids with and without these QTLs showed that QTL-based hybrids were significantly, but modestly, higher yielding in a series of terminal drought stress environments (Bidinger *et al.*, 2005b). However, this gain under stress was achieved at the cost of a lower yield in the non-drought environments. This observed association of LG2 drought tolerance with reduced yield performance in favourable non-stress environments was in agreement with the report of Yadav *et al.*, (2003) that LG2 alleles of drought sensitive parent H 77/833-2 conferred greater tillering, grain yield and stover yield than LG2 alleles of drought tolerant parent PRLT 2/93-33 in test cross hybrids grown in very favourable, high yielding non-stress environments. In any case, this major QTL mapped on LG2 accounted for up to 32% of the phenotypic variation in test cross grain yield under post-flowering drought stress environments (Yadav *et al.*, 2002; Bidinger *et al.*, 2007). In addition, a number of other QTLs were detected that were associated with maintenance of grain-yield determining component traits (Yadav *et al.*, 2011).

The PRLT allele for the LG2 drought tolerance QTL (Yadav *et al.*, 2002) has been transferred to drought sensitive pearl millet lines through marker assisted backcross breeding (Serraj *et al.*, 2005). Several introgressed lines carrying LG2 genomic region exhibited positive general combining ability (GCA) for grain yield under terminal heat stress which was associated with a higher panicle harvest index (Yadav et al., *2011*). Physiological dissections indicated that lines having QTLs had lower transpiration rate as compared to lines not carrying this QTL (Kholová *et al.*, 2010). There are reports that the LG2 QTL is also associated with salinity tolerance (Sharma et al., 2011), presumably as a result of its effects on transpiration rate.

Stover quality

Efforts are underway to use marker-assisted breeding for enhancement of stover quality (Hash *et al.*, 2003). Two QTLs one each on LG2 and LG6 has been identified which govern several fodder quality traits. Fortunately, QTL on LG2 was also associated with improved drought tolerance. Thus transferring this stover quality QTL is also likely to improve drought tolerance, which would be an additional benefit for arid zone environments (Nepolean *et al.*, 2006). Marker assisted backcross transfer of an additional stover quality QTL on LG4 (with favorable alleles from 863B) into the genetic background of ICMB 95222, and subsequent comparison of hybrids of the introgression lines with HHB 146, which has as its seed parent ICMA 95222, showed that the improved stover quality conferred is likely due to improved host plant resistance to blast (Nepolean *et al.*, 2010). This stover quality QTL maps to a position similar to those previously reported for rust resistance from ICMP 83506 (Morgan *et al.,* 1998) and downy mildew resistance from 863B (Hash and Witcombe, 2001). Further attempts to introgress this genomic region from 863B into the genetic background of elite pollinator J 2340 by marker assisted backcrossing, suggest that the blast and downy mildew resistance alleles from 863B may be linked to alleles for rust susceptibility.

Cultivar development

Earlier efforts in pearl millet improvement in India concentrated on the utilization of local germplasm material. Using simple mass selection, a few varieties were developed. The introduction of material in 1960s from African countries yielded useful varieties for Indian conditions. Jamnagar Giant, Improved Ghana and Pusa Moti were developed by selection from African introductions.

Since pearl millet is a highly cross-pollinated crop and displays a high degree of heterosis for grain and stover yields, attempts were made in the 1950s to exploit heterosis in hybrids by utilizing the protogynous nature of flowering to produce chance hybrids and to raise crop productivity. The usual method at that time for production of hybrid seeds was growing the parental lines in mixture and allowing them to cross-pollinate. The resultant seed contained approximately 40% hybrid seed when the two parental lines flower at about same time. The chance hybrids, however, could not become popular due to their limited superiority over OPVs, narrow range of adaptation and lack of seed production programmes.

Exploitation of heterosis became a reality with the discovery of cytoplasmic-nuclear male sterility and release of male-sterile lines Tift 23A and Tift 18A in early 1960s at Tifton Georgia, USA. These lines were made available to Indian breeding programmes. The male-sterile line Tift 23A was extensively utilized because of its relatively shorter plant stature, profuse tillering, uniform flowering and good combining ability. As a result a few hybrids based on this line were released between 1965 and 1969. One of these hybrids (HB 3), became highly popular and was extensively cultivated because of its early maturity, bold grains and adaptation to drought.

Intensive cultivation of hybrids based on a single male-sterile line, however, led to downy mildew epidemic in the mid 1970s. Hence multiplication of hybrids based on Tift 23A was discontinued. Two new hybrids BJ 104 and BK 560 produced on seed parent 5141A bred at IARI, New Delhi became popular in pearl millet growing areas. These hybrids were widely cultivated during 1977-1984, but a high incidence of downy mildew on 5141A and the resultant susceptibility of both hybrids caused 5141A to be phased out as a seed parent in 1985 (Govila *et al.,* 1997).

A critical appraisal of the situation reveals that downy mildew epidemics in mid 1970s and 1980s were mainly due to lack of diversity in the parental lines of hybrids. Initially all hybrids were first based on Tift 23A, and then on 5141A. Similarly, the same pollinators were also repeatedly used in combinations with different male-sterile lines. Three restorers (J 104, K 560 and K 559) were male parents of nine commercial hybrids. Similarly, Haryana Agricultural University utilized only two restorers (H90/4-5 and H77/833-2) in developing and releasing five hybrids. These facts indicate that outbreaks of downy mildew were due to a narrow genetic base among seed parents and restorers, rather than any undesirable effects of A_1 cytoplasm (Yadav *et al.,* 1993).

Experiencing recurrent problems of downy mildew in hybrids in 1970s and 1980s, AICPMIP and ICRISAT responded by increasing the efforts to breed open pollinated varieties (OPVs) and by strengthening the research to diversify the genetic base of seed parents. As a result many OPVs like ICTP 8203, WC-C75, HC 4, ICMV 155, ICMV 221, CZP 9802 and Raj 171 were adopted by growers at a large scale. Contrary to hybrids, there is no risk of breakdown of resistance of OPVs to downy mildew. The OPVs are currently being released for risk-prone areas where replanting is a common practice.

Efforts in the diversification of seed parents led to the development and use of a large number of seed parents. During 2008-011, each year new hybrids based on 35-37 A-lines (designated) from public sector and 46-63 A lines (by name) from private sector have been contributed for coordinated evaluation in AICPMIP trials. The new hybrids that have been tested for the same period are based on 40-56 R-lines from public sector and 48-75 R-lines from private sector. Utilization of such large number of parental lines in hybrid breeding ensured that no further downy mildew epidemics have occur during last 25 years, although individual hybrids have succumbed to this disease.

Table-20: Number of hybrids evaluated in AICPMIP trials during 2008-11 contributed by public and private sectors and number of male-sterile (A) and restorer R lines used in their development.

Year	No of Hybrids		A-lines		R-lines	
	Public	Private	Public	Private	Public	Private
2008	71	56	37	46	56	48
2009	62	70	37	54	50	59
2010	55	81	35	63	43	75
2011	51	68	36	54	40	63

Using diverse male-sterile lines and pollinators, a large number of hybrids have been released in the last 25 years by both public and private sectors. More than 150 improved cultivars were released since 1986. Three-fourth of these was hybrids which show that hybrid breeding has been a major priority in India in pearl millet improvement. The number of releases over a period of 25 years indicates that, on an average, 3-4 hybrids are released each year for general cultivation for different agro-ecological zones. In addition, a large number of private sector hybrids were also commercialized as truthfully labelled seed. This has enabled farmer to choose from a wide range of available cultivars with appropriate trait-combinations that he considers fit to meet his requirement in different crop production environments of various states. In addition, availability and cultivation of a large number of hybrids provides buffering mechanism against diseases, insect-pests and environmental vagaries. Hybrids like MH 179, Pusa 23, GHB 30, HHB 60, HHB 67, MLBH 104, MBH 110, Eknath 301, ICMH 356, Shradha, Saburi, JKBH 26, 7686, 7688, HHB 67 Improved, RHB 121, GHB 538, GHB 558, GK 1004, Proagro 9444 and 86M64 and OPVs like WC-C 75, Raj 171, ICMV 155, ICMV 221, ICTP 8203, CZP 9802 and JBV 2 became very popular with farmers. Currently more than 125 hybrids (by name) developed by both public and private sectors are in market.

Both public and private sectors are involved in the development of hybrids for various production environments. However, public sector mainly targets rain fed ecology of more marginal environments, while private sector has greater priority for better-endowed environments in their hybrid development programme. Since 1986, 53 hybrids from public sector and 35 from private sector have been notified for different regions.

2.6 Seed Scenario

The State-wise Seed Replacement Rate of pearl millet is given in **Table-21.**

Table-21: State-wise Seed Replacement Rate (SRR) of pearl millet during 2006 to 2012.

Sl. No.	State	Seed Replacement Rate (%)						
		2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
1.	**Andhra Pradesh**							
	Variety	67	85	46	51.02	52.50	53.20	
	Hybrids	100	100	100	100	100	100	100
2.	**Karnataka**							
	Variety	29	28	29	29.94	39.23	38.20	38.71
	Hybrids	100	100	100	109.73	100	100	100
3.	**Tamil Nadu**							
	Variety	-	85	91	96.10	72.14	3.68	4.93
	Hybrids	-	-	-	-	-	-	-
4.	**Gujarat**							
	Variety	-	-	-	-	-	-	-
	Hybrids	100	100	100	100	100	100	100
5.	**Maharashtra**							
	Variety	75	74	92	93.81	93.75	98.6	95.91
	Hybrids	100	100	100	100.02	99.89	100.33	99.63
6.	**Rajasthan**							
	Variety	46.22	42.09	56.63	46.28	69.44	57.28	64.69
	Hybrids	-	-	-	-	-	-	-
7.	**Madhya Pradesh**							
	Variety	55.37	48.22	50.25	69.35	57.24	73.23	87.96
	Hybrids	-	-	-	-	-	-	-
8.	**Uttar Pradesh**							
	Variety	51.89	57.30	77.95	73.83	96.69	71.03	71.59
	Hybrids	-	-	-	-	-	-	-
9.	**Haryana**							
	Variety	57.51	60	66	76.69	79.45		
	Hybrids	-	-	-	-	-	-	-
ALL INDIA								
Variety		**55.10**	**48.97**	**62.92**	**48.85**	**61.43**	**33**	**56.67**
Hybrids		-	-	-	-	-	-	-

Source: Seednet India portal.

2.7 Recommended package of practices

(a) Recommended package of practices by ICAR/SAUs for pearl millet

1.		**Time of sowing**
	Kharif	In Zone A_1 : Up to mid July, Zone A and B: Last week of June to 1st week of July
	Summer	Zone A: Up to second fortnight of February , Zone B: First fortnight of March
2.	**Method of sowing**	
	Mechanized (%)	100
3.	**Seed**	
	Seed Rate	4 Kg/ha
	Row to row distance(cm)	Zone A 1: 60 cm Zone A and Zone B : 45 cm
	Plant to plant distance	10-15cm
	Ideal plant population/ha	Zone A1: 1.25 Lac Zone A and B: 2.25 Lac
	Seed treatment	Given below under disease management
	Fungicides (Name & Dose)	Given below under disease management
	Bio-fertilizer (Name & Dose)	Seed treatment with Azospirrilum @ 01 packet/acre and PSB @ 01 packet/acre
4.		**Fertilizer dozes (Kg/ha)**
	Kharif	
	N :P: K(Kg/ha) Rainfed	(N:P) Zone A1: 40:20 Zone A:Gujarat: 80:40, Haryana: 40:20, Jaipur: 60:30, U.P. 80:40 Zone B; Maharashtra 60:40, Karnataka :50:20, A.P.:50:20, Tamil Nadu:80:40
	Irrigated	Zone A 1 : 60:30 Kg/ha, Zone A: Jaipur: 80:40 Kg/ha, Hissar: 120:60 Kg/ha
	K	-Nil-
	Micro-nutrient	10 Kg/ha $ZnSO_4$ or spray 2% $ZnSO_4$ in Zinc deficit soils
	Manures (FYM)	5.0 Ton/ha
	N:P (Kg/ha)	120:40
5.	**Weed Control**	
	Name of major weeds	Amaranthus (viridus and spinosis), Cyperusrotandus, Cenchrusbiflorus, Tribulis spp. Digeraarvensis, Celotiaargensis, Euphorbia spp.
	Control Measures	Manual hoeing/weeding at 20 and 40 days after sowing

	Name of weedicides	Atrazine, 2-4 D
	Doses (Lit/Kg)	Atrazine : 0.5-1.0 Kg/ha; 2-4 D @ 0.5-0.75 Kg/ha
	Time of Applications	Atrazine: pre emergence; 2-4 D: post emergence (30-35 DAS)
	Method of Applications	Spray solution
6.	**Disease Management**	
	Name of major disease	Downy mildew: *Sclerospora graminicola*(Sacc.) Schrot
	Control Measures	Use of resistant cultivars ● Rotate hybrids with variety alternately to keep soil inoculum under control.
	Name of insecticides & doese	Apron 35 SD @ 6g/ kg seed; *Bacilluspumulis* (INR7); Chitosan @ 10g/kg seed; Ridomil 25 WP @ 100 ppm foliar spray
7.	**Pest Management**	
	Name of major disease / pest Control Measures Name of insecticides Doses (Lit/Kg) IPM	**Shoot fly and stem borer**: Seed treatment with imidacloprid 600 FS @ 8.75 ml/kg seed followed by dusting of fenvelerate 0.4% @ 20 kg/ha or spraying of NSKE 5% at 35 days after germination was effective for the management of shoot fly and stem borer in pearl millet. **White grub**: As per package of practices (PoP) for the Zone-IIIa of Rajasthan, application of carbofuran 3% or quinalphos 5% granules @ 12 kg/ha at the time of sowing is recommended. A cost of effective technology is in pipeline i.e. seed treatment with clothianidin 50 WDG @ 7.5 g/kg seed or imidacloprid 600 FS @ 8.75 ml/kg seed found effective (2.08 to 3.88% plant damage as compared to 13.91% plant damage in untreated) against white grub in pearl millet. **Grass hopper, grey weevil and chafer beetle**: Dusting of quinalphos 1.5% or methyl parathion 2% @ 25 kg/ha at the time of pest appearance is recommended in PoP Zone IIIa. Insect pest management: An IPM module, seed treatment with imidacloprid 600 FS @ 8.75 ml/kg seed, fishmeal trap @ 10/ha and spraying of NSKE 5% at ear head stage showed significant results for the management of pest complex of pearl millet (Experiment is under progress).
8.	**Harvesting & Threshing**	
	Kharif	Sept 2^{nd} fortnight to October
	Rabi/Summer	May last week to June first fortnight
	Harvesting	100% by manual
	Threshing	100% by threshers

(b) Recommended production technology for different States

Rajasthan

- Use improved varieties recommended for the State.
- Adopt line sowing using a seed-drill having floated roller metering device to improve germination and avoid crust formation.
- Spreading of 5 ton FYM/ha above seed furrows helps to combat crust problem and improve seed germination.
- Adopt wider row spacing of 60 cm where rainfall is less than 400 mm and 45 cm row spacing where rainfall is more than 400 mm.
- Sow crop at 60 cm row spacing maintaining 1.1 to 1.6 lakh plants/ha in areas receiving less than 400 mm rainfall and at 45 cm row spacing maintaining 1.5 to 2.2 lakh plants/ha in areas receiving more than 400 mm rainfall.
- Apply 40:20 kg/ha N: P_2O_5 in areas receiving less than 400 mm rainfall & 60-80:30 kg/ha N: P_2O_5 in areas getting more than 400 mm rainfall.
- Whole amount of P and 50% of recommended N should be drilled below the seed and remaining amount of N should be top dressed 3 to 4 weeks after sowing coinciding with rains.
- In case of prolonged drought skip top dressing of N and spray of 2% urea.
- Application of 25% recommended dose of fertilizers (RDF) through organic and 75% RDF through inorganic nutrient sources maintains soil health and sustain higher crop productivity.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue out diseased seedlings, if any.
- Keep field free from weeds for first 30 days either with hand weeding and hoeing or application of Atrazine @ 0.5 kg a.i./ha as pre-emergence spray followed by one weeding and hoeing at 4-6 weeks of sowing.
- Convert part of the land into catchment area to harvest rain water and use it to provide protective irrigation at flag leaf /grain filling stages to avoid moisture stress situation in case of prolonged drought.
- Uproot every third row and use as mulch in case of prolonged (30-40 days) drought before flowering.
- Spray Atrazine (100ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Mixed one kg carbofuran 3% or quinolphos 5% per three kg seed or apply phorate 10 G or quinolphos 5% or carbofuran 3% or sevidol 4% @ 25 kg/ ha. to control white grub.
- Follow 2:1 pearl millet + cluster been/moth bean intercropping system in areas receiving <400 mm rain fall and adopt 2:1 pearl millet +cowpea/ greengram intercropping system in areas getting >400 mm rainfall to ensure maximum returns in normal years or to cover risk due to failure of monsoon or provide supplemental pulse proteins and additional income.
- Pearl millet should be sown after legume crops like cluster bean, moth bean in rotation to maintain soil fertility and crop productivity.

Maharashtra

- Use improved varieties recommended for the State.
- Timely sowing (up to mid July) should be done or do dry sowing before onset of monsoon.
- Drill sow in ridges and furrows 45 cm apart with 'Furrow cum Seed Drill' particularly in lighter type of soils for water harvesting and

good germination. Drill sow at 45 cm in medium deep soils.

- Maintain optimum plant population of 1.75 to 2 lakhs/ha with 4 kg/ha seed.
- Fertilize with 30-40 kg P_2O_5/ha basal dose and 40 to 60 kg N/ha be applied in 2 splits, half as basal and the second half 3 to 4 weeks later synchronizing with rains.
- Apply 10 kg or spray 2% $ZnSO_4$/ha to correct zinc deficiency.
- Apply 20 kg N/ha as additional dose under excessive rains at vegetative stage.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- To maintain soil health and sustain high pearl millet productivity apply recommended dose of nutrients through organic & inorganic sources at 25:75 ratio.
- Keep field weed free for the first 30 days either with weeding and hoeing or application of Atrazine @ 0.5 a.i./ha as per-emergence spray followed by one weeding and hoeing at 4 to 6 weeks.
- Dust mulching or make ridge & furrow after 25-30 days of sowing to conserve and harvest rain water.
- Convert part of the land into catchment area to harvest rain water and use it to provide protective irrigation at flag leaf/grain filling stages to avoid moisture stress situation in case of prolonged drought.
- Uproot every third row to reduce plant population and use it as mulch in case of prolong (30 to 40 days) drought before flowering to escape complete crop failure.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/ improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i./kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Follow 2:1 pearl millet + red gram/black gram/ green gram/cowpea intercropping system.

Gujarat

- Use improved varieties recommended for the State.
- Line sow with a drill at 45-60 cm row spacing.
- Maintain optimum plant population of 1.8 to 2.2 lakh/ha.
- Fertilize with 80 kg N/ha in 2 splits, half at sowing and half 3-4 weeks later synchronizing with rainfall. Apply 40 kg P_2O_5 /ha basally.
- Sowing should be done in 2nd fortnight of February for summer crop.
- Summer crop should be fertilized with 120 kg + 60 + 20 kg (N:P_2O_5: $ZnSO_4$)/ha. N should be applied in three equal splits 1/3rd at sowing along with P & $ZnSO_4$, 1/3rd at tillering & 1/3rd at boot leaf stage.
- Adopt integrated nutrient management to maintain soil health and sustain high pearl millet productivity.
- Use *bio* fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue diseased seedlings, if any. Thin and transplant healthy seedlings in gaps.
- Keep field weed free-for the first 30 days with weeding and hoeing or application of Atrazine @ 0.5 kg a. i./ha a pre-emergence spray followed by one weeding and hoeing at 4-6 weeks.
- Dust mulching after each effective rainfall to manage weeds and conserve soil moisture.
- Convert part of the land into catchment and use

the runoff water for protective irrigation at flag leaf/grain filling stages.

- Apply irrigation at 0.75 to 1.0 IW/CPE ratio in summer pearl millet.
- Uproot every third row and use as mulch in case of prolonged (30 to 40 days) drought before flowering to save the crop from total failure.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/ improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i./kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Follow 2:1 pearl millet + green gram/cowpea intercropping system.

Uttar Pradesh

- Use improved varieties recommended for the State.
- Apply N:P_2O_5:K @ 80:40:30 kg/ha. Whole amount of P & K and half of N should be drilled below seed at the time of sowing & remaining N should be top dressed 3-4 weeks after sowing coinciding with rains.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue diseased seedling, if any. Thin and transplant healthy seedlings in gaps.
- Keep field weed free for the first 30 days either with weeding and hoeing or application of Atrazine @ 0.5 kg a.i./ha as pre-emergence spray followed by one weeding and hoeing at 4-6 weeks.
- Give protective irrigation, particularly at flag leaf and grain formation stages.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf andg rain formation stages.
- Use more than one hybrid/improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i./kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Follow 2:1 pearl millet + cowpea/moongbean intercropping system.

Haryana

- Use improved varieties recommended for the State.
- Sow in ridges and furrows 45 cm apart or line sow with a drill having floated roller metering device to avoid crust formation and enhance germination.
- Maintain 1.75 to 2.2 lakhs plants/ha. Thin and fill gaps 3-4 weeks after sowing on a rainy day and transplant 3 weeks old seedlings up to mid-August if rains are delayed or do not permit sowing.
- Apply 40:20 kg N:P/ha in rainfed & 120:60 kg N:P in irrigated conditions. In irrigated situation N should be applied in 3 splits, half at the time of sowing as basal dose, one fourth at 3 weeks and one fourth at 6 weeks after sowing coinciding with rain. Under rainfed conditions N should be applied in two splits (half basal & half top dressed 3-4 weeks after sowing).
- Apply 25 kg/ha zinc sulphate also if not applied to preceding crop.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Apply nutrients through integration of organic & inorganic sources (25:75).

- Rogue diseased seedling, if any. Thin and transplant healthy seedlings in gaps to maintain plant population.
- Keep field weed free for the first 30 days either with weeding and hoeing or Atrazine @ 1.0 kg/ha as pre-emergence spray followed by one weeding and hoeing at 4-6 weeks.
- Dust mulching after each effective rainfall manage weeds & conserve soil moisture
- Convert part of the land into catchment area to harvest rain water and use it to provide protective irrigation at flag leaf/grain filling stages to avoid moisture stress situation in case of prolonged drought.
- Uproot every third row and use as mulch in case of prolonged (30 to 40 days) drought before flowering.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i./kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Mixed one kg carbofuran 3% or quinolphos 5% per three kg seed or apply phorate 10 G or quinolphos 5% or carbofuran 3% or sevidol 4% @ 25 kg/ha to maintain white-grub infestation.
- Follow 2:1 pearl millet: cluster bean/green gram/cowpea intercropping system.

Karnataka

- Use improved varieties recommended for the State.
- Line sow with a drill keeping 45 cm row spacing.
- Maintain 1.8 to 2.2 lakh plants/ha.
- Apply N:P_2O_5 @ 50:20 Kg/ha. N should be applied in two splits half at sowing drilled below the seed and other half at 3-4 weeks after sowing coinciding with rains.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue diseased seedling, if any. Thin and transplant healthy seedlings in gaps.
- Keep field weed free for the first 30 days either with hand weedings/hoeings or Atrazine @ 0.5 kg a.i./ha as pre-emergence spray followed by one weeding/hoeing at 4-6 weeks.
- Apply dust mulching after each effective rain fall to manage weeds and conserve soil moisture.
- Convert part of the land into catchment area to harvest rain water and use it to provide protective irrigation at flag leaf/grain filling stages to avoid moisture stress situation in case of prolonged drought.
- Uproot every third row and use it as mulch in case of prolong (30 to 40 days) drought before flowering.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i./kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Follow 2:1 pearl millet + red gram/green gram/intercropping system.

Andhra Pradesh

- Use improved varieties recommended for the State.
- Sowing should be done up to mid July.
- Drill sow in ridges and furrows 30 cm apart

particularly in lighter type of soils. Drill sow at 45 cm in medium deep soils.

- Maintain 1.75 to 2 lakh plants/ha with 4 kg/ha seed.
- Apply 40 kg N/ha in 2 splits, half basal and second half 3-4 weeks later coinciding with rains.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue diseased seedling, if any. Thin and transplant healthy seedlings in gaps.
- Keep field weed free for the first 30 days either with hand weeding/ hoeing or Atrazine @ 0.5 kg a.i./ha as pre-emergence spray followed by one weeding/hoeing at 4-6 weeks.
- Apply dust mulching after each effective rain fall to manage weeds and conserve soil moisture.
- Convert part of the land into catchment area to harvest rain water and use it to provide protective irrigation at flag leaf/grain filling stages to avoid moisture stress situation in case of prolonged drought.
- Uproot every third row and use it as mulch in case of prolong (30 to 40 days) drought before flowering.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i. /kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Mix FYM with BHC 10% in 3:2 proportions and apply @ 100 kg/ha before sowing to control white grub infestation.
- Follow 2:1 pearl millet + red gram/horse gram intercropping system.

Tamil Nadu

- Use improved varieties recommended for the State.
- Line sowing at 45 cm row distance with drill or transplant 3 week old seedlings.
- Maintain 1.75 to 2.2 lakhs plants/ha.
- Apply 80:40 kg N: P_2O_5/ha. N should be applied in 2 splits, half basal and half 3-4 weeks later synchronizing with rainfall.
- Apply nutrients by integrating organic and inorganic sources of nutrients at the ratio of 25:75.
- Use bio fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue diseased seedling, if any. Thin and transplant healthy seedlings in gaps.
- Keep field weed free for the first 30 days either with hand weedings/ hoeings or Atrazine @ 0.5 kg a.i./ha as pre-emergence spray followed by weeding/hoeing at 4-6 weeks.
- Reduce plant population by 33% by uprooting every third row and use it as mulch in case of prolong (30 to 40 days) drought before flowering.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrid/ improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i./kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Follow 2:1 pearl millet + green gram/cowpea intercropping system.

Madhya Pradesh

- Use improved varieties recommended for the State.
- Line sow with drill 45 cm apart.
- Maintain 1.75 to 2 lakhs plants/ha.
- Apply N: P_2O_5 @ 40:20 Kg/ha. The N should be applied in two splits, half basal along with whole amount of P_2O_5 at the time of sowing and remaining half 3-4 weeks later coinciding with rainfall.
- Use bio-fertilizers to improve nutrient use efficiency and increase availability of N and P.
- Rogue diseased seedling, if any. Thin and transplant healthy seedlings in gaps.
- Keep field weed free for the first 30 days either with hand weedings/hoeings or Atrazine @ 0.5 kg a.i. /ha as pre-emergence spray followed by one weeding/hoeing at 4-6 weeks.
- Uproot every third row and use as mulch in case of prolong (30 to 40 days) drought before flowering.
- Spray Atrazine (100 ppm) or Kaoline (6%) at 15 days interval if drought occurs between flag leaf and grain formation stages.
- Use more than one hybrids/ improved varieties in the same year or rotate hybrids/improved varieties in alternate years to check the spread of downy mildew.
- Use Apron 35 SD @ 2 g a.i. /kg of seed followed by Ridomil 25 WP (1000 ppm) spray 20 days later to check downy mildew disease occurrence and to eliminate soil inoculum.
- Follow 2:1 pearl millet + red gram/cowpea intercropping system.

Pearl millet diseases and their management

Major diseases of pearl millet:

1. Downy mildew : *Sclerospora graminicola* (Sacc.) Schroet.
2. Smut : *Moesziomyces penicillariae* (Bref.) Vanky.
3. Rust : *Puccinia substriata* var. p*enicillariae.* (Zimm.)
4. Ergot : *Claviceps fusiformis* (Loveless)
5. Blast : *Pyricularia grisea* (Cooke) Sacc [telemorph:

   Magnaporthagrisea (Herbert) Barr.]

Downy mildew (DM)

Downy mildew is widely distributed in all the pearl millet growing area in the world. Systemic symptoms as chlorosis generally appear on the second leaf and all the subsequent leaves and panicles of infected plant show symptoms. Leaf symptoms begin as chlorosis at the base of the leaf lamina and successively higher leaves show a progression of greater leaf area coverage by the symptoms. Infected chlorotic area produce massive amount of asexual spores, generally on the lower surface giving the leaf a 'downy' appearance.

Systemically infected plants remain stunted either do not produce panicle or produce malformed panicles. In many affected plants 'green ear' symptoms appear on the panicles due to the transformation of floral parts into leafy structure that may be total or partial and such plants do not produce seed or produce very few seeds. The infected leaves produce sexual spores (oospores) in the necrotic leaf tissue late in the season.

Currently in India about 50% of the 9 million ha under pearl millet cultivation is grown with more than 70 hybrids in which DM incidence has been highly variable, with some hybrids showing more than 90% incidence at farmer's field. This disease can assume alarming levels when a single genetically uniform pearl millet cultivar is repeatedly and extensively grown in a region. Yield losses within the region can reach 30-40% (Thakur *et al.*, 2003; Rao *et al.*, 2007).

Rust

Rust symptoms first appear on lower leaves as typical pustules containing reddish brown powder (uredospores). Later, dark brown teliospores are produced. Symptoms can occur on both upper and lower surface of the leaves but mostly on upper surface and also on stem. Highly susceptible cultivars develop large pustules on leaf blades and sheaths.

Rust has generally been considered as a relatively less important disease in most of the pearl millet growing areas than downy mildew, ergot and smut because of its appearance, generally after the grain-filling stage, causing little or no loss in grain yield. Worldwide this disease is probably of greater importance to multi cut forage hybrids where even low rust severities can result in substantial losses of digestible dry matter yield (Wilson *et al.*, 1991).

Smut

Smut disease is of greater importance in India especially with the adaptation of hybrids. The disease is more severe in CMS-based single-cross hybrids than in open-pollinated varieties. The infected florets produce sori that are larger than grains and appear as oval to conical, which are initially bright green but later turn brown to black. The estimated grain yield loss due to smut is 5-20% (Thakur and Chahal, 1987). The disease occurs during the month of September/October. Early sown crop generally escapes from the smut infection.

Ergot

The disease is easily identified as a honeydew substance of creamy to light pinkish ooze out of the infected florets which contains numerous conidia. Within two weeks these droplets dry out as hard dark black structures larger than seeds, protruding out from the florets in place of grain, which are called sclerotia. Here the loss in grain yield is directly proportional to the percentage of infection as the infected seed is fully transformed into sclerotium. The disease occurrence and spread is highly influenced by weather conditions during the flowering time. It became more important due to cultivation of genetically uniform single-cross F1 hybrids based on cytoplasmic male-sterility system in India.

Blast

The disease is known as leaf spot of pearl millet, caused by *Pyricularia grisea* (Cooke) Sacc. [telemorph: *Magnaportha grisea* (Herbert) Barr.] has become a serious disease during the past few years. The disease affects both quality and production of forage and grain. The symptoms appear as distinct large, indefinite, water soaked, spindle shaped, grey centred and purple grey horizon with yellow margin, resulting in extensive chlorosis and premature drying of young leaves.

Highly effective field and greenhouse screening techniques that can easily and precisely differentiate between resistant and susceptible progenies have been developed for pearl millet diseases and are being used extensively worldwide.

Managing pearl millet diseases

The diseases of pearl millet may be controlled by various control methods such as chemical, biological or cultural practices. The approaches are:

Downy mildew

- Use of resistant cultivars.
- Rotate hybrids with variety alternately to keep soil inoculum under control.
- Seed treatment with Apron 35 SD @ 6g/kg seed.
- Seed treatment with *Bacillus pumulis* (INR7.)
- Seed treatment with Chitosan 10g/kg seed.
- Foliar spray of Ridomil 25 WP (100 ppm) after 21 days of sowing if infection exceeds 2-5%.
- Rogue out infected plants and bury or burn.
- Seed treatment with Ridomil MZ-72 @ 8g/kg seed and a foliar spray of Ridomil MZ-72 2g/l.

Rust

- Use of resistant hybrids/varieties.
- Sow the crop with the onset of monsoon.
- Destruction of collateral hosts like *Ischaemum pretosum* and *Panicum maximum* on the field bunds.
- Dusting of fine sulphur @ 17kg/ha and two sprays of 0.2% Mancozeb at 15 days intervals.

Smut

- Use of resistant cultivars.
- Spray with Captafol (2ppm) followed by Zineb (2ppm) on panicle at boot leaf stage which reduces infection.
- Remove smutted ear from the field.

Ergot

- Mechanical removal of sclerotia from seed and washing of seed in 2% salt water.
- Adjust sowing dates so that ear emergence does not coincide with more rainy days.
- Plough the field soon after harvest so that ergot is buried deep.
- Three foliar application of Thiram 0.2% or Copper Oxychloride 0.25% or Ziram @ 0.2% starting from 50% flowering.

Major insect pest of pearl millet crop

Pest problem of millets are generally under estimated. There are many important pests of pearl millet causing losses from 10-80%. Infestation by shoot fly, white grub, stem borer, Helicoverpa and grass hopper is main constrain in pearl millet growing area. Similarly root bug is a sporadic pest causing heavy economic loss in the field during epidemic. Grey weevil and leaf roller damage is also increasing as compared to previous years. During 2011 and 2012, chafer beetle was also observed on crops of pearl millet at Research Farm, Durgapura, Jaipur.

The survey data generated from farmers' field of the Zone-IIIA of Rajasthan during last few years indicated gradual increase in pest population year-by-year. Alarming incidence of shoot fly (45% dead heart at seedling stage of an unknown hybrid of Ganga Kaveri at village Balken (Udaipuria Mor of Govindgarh tehsil of Jaipur district) had been observed during kharif, 2011. Similarly at village Boraj of tehsil Sanganer of district Jaipur, 20% dead heart caused by shoot fly was recorded in variety Pioneer 86M86 during kharif, 2012.

More than 70% damage of seedling stage due to whitegrub was recorded at village Aloda (Meelo Ki Dhani) of Tehsil DantaRamgarh of District Sikar during kharif, 2011. More than 80% plant damage due to white grub was observed at village Ramsinghpura, Boraj of tehsil Sanganer of Jaipur during kharif, 2012.

About 60% damage due to grass hopper was noticed at village Bansko of Bassi tehsil of Jaipur district during kharif, 2011. More than 20% damage due to grass hopper was also recorded at KethunMor (Chaksu, Jaipur) during kharif, 2012. About 10% infestation due to stem borer was recorded at Rajawas (Amber, Jaipur), Bagawas (Phulera, Jaipur) and Bhadana (Dausa) during survey in different years.

Control measures

Shoot fly and stem borer: Seed treatment with imidacloprid 600 FS @ 8.75 ml/kg seed followed by dusting of fenvelerate 0.4% @ 20 kg/ha or spraying of NSKE 5% at 35 days after germination was effective for the management of shoot fly and stem borer in pearl millet.

White grub: As per package of practices (PoP) for the Zone-IIIa of Rajasthan, application of carbofuran 3% or quinalphos 5% granules @ 12 kg/ha at the time of sowing is recommended.

A cost effective technology is in pipeline i.e. seed treatment with clothianidin 50 WDG @ 7.5 g/kg seed or imidacloprid 600 FS @ 8.75 ml/kg seed found effective (2.08 to 3.88% plant damage as compared to 13.91% plant damage in untreated) against white grub in pearl millet.

Grass hopper, grey weevil and chafer beetle: Dusting of quinalphos 1.5% or methyl parathion 2% @ 25 kg/ha at the time of pest appearance is recommended in PoP Zone IIIa.

Insect pest management: An IPM module, seed treatment with imidacloprid 600 FS @ 8.75 ml/kg seed, fishmeal trap @ 10/ha and spraying of NSKE 5% at earhead stage showed significant results for the management of pest complex of pearl millet (Experiment is under progress).

2.8 Cropping System

In northern India many rotations of crops involving Pearl millet are feasible crops like wheat, barley, chick pea, potato and toria can be grown after harvest of Pearl millet in irrigated areas. Some of the most important cropping system are given below:

1. Pearl millet – Barley
2. Pearl millet – Wheat
3. Pearl millet – Chick pea
4. Pearl millet – Field pea
5. Pearl millet – Potato
6. Pearl millet – Potato – Wheat
7. Pearl millet – Toria – Wheat
8. Pearl millet – Wheat – *Moong* (Green gram)
9. Pearl millet – Wheat – *Jowar* (fodder)
10. Pearl millet – Wheat – Pearl millet (fodder)

In rainfed areas of northern India Pearl millet is grown mixed with groundnut, *til*, *urd* and *moong*. Recently in intercropping system two crops differing in height canopy, adaptation and growth habits are grown so that they accommodate each other with the least competition. Intercropping of groundnut or castor with hybrid *Bajra* has given good returns at Hisar (Haryana) and intercropping of *Moong* with *Bajra* (two rows of *Moong* in between two rows of *Bajra*) has given additional 3 quintals yield of *Moong* at I.A.R.I. New Delhi and also two rows of cowpea produced about 90 quintals of green fodder within 45 days.

2.9 Crop products

Technologies for various processing treatments, such as milling, malting, blanching, acid treatment, dry heating and fermentation, which reduce anti-nutritional factors and increase the digestibility and shelf life various alternative food products such as unleavened flat bread (roti/ chapati), porridges, noodles, bakery products and extruded and weaning food products have been developed and tested at the laboratory scale.

Grain processing technologies

Dehulling: Both whole grains and dehulled (decorticated) grains of pearl millet are used for preparing various types of food products. Decortications is generally to the extent of removing 12-30% of the outer grain surface. Increased decortications lead to greater loss of fibre, ash and fat. It also reduced protein, lysine, histidine and arginine. Decorticated grains improve the nutritional quality and sensory properties of various food products, but these also have cost consideration in terms of the time and investment and grain weight losses. Further, these also lead to micronutrient losses, which are more concentrated in the outer layers of the grain. Pearl millet grains can be decorticated in rice mills or other modified mills. In some villages and urban areas, pearl millet grains are decorticated with abrasive disks in mechanical dehullers.

Milling: Grains can be milled either by using a hammer mill or a roller mill. The flour produced using a hammer mill has large particle size and is not uniform; hence it is suitable for preparing thin and stiff porridge of rough texture and not suitable for preparing baked and steamed food products of smooth texture. A new method for improving the shelf life of pearl millet has been developed at the Central Food Technological Research Institute (CFTRI) Mysore. It involves moist heating of the grains followed by drying to about 10-12% moisture and decortications to the desired degree or pulverization. This process improves the milling characteristics of pearl millet varieties which have high proportions of floury endosperm. Flour from treated and decorticated pearl millet could be stored for about 3-4 months, during which the free fatty acid (FFA) content remained below 10%, which is the limit of perceptible deteriorative condition. The oxidative rancidity also remains low, as the flours are refined. Another advantage of this process is that the microbial load on the grain surface is drastically reduced.

Malting: This process involves limited germination of cereal in moist air under controlled conditions. For pearl millet, a malting procedure has been developed that involves soaking of grain in 0.1% formaldehyde solution for 6 hours, followed by aeration for 3 hours and re-steeping in fresh formaldehyde solution for 16 hours. The grains are then germinated for variable periods 12, 24, 36, 48 and 72 hours, after which the grains are dried in an oven and vegetative growth is removed by abrasive action. Malting helps in the mobilization of seed reserves and elaboration of the activity of á and ß amylase and protease. Malting reduces protein, but improves the quality of protein compared to that in the bran, so a small loss in protein in milling of the malted pearl millet is compensated by protein quality (Malleshi and Klopfenstein, 1998). The process results in a higher protein efficiency ratio and bioavailability of minerals (Rao, 1987). As compared to the high levels of polyphenols (755 mg 100^{-1} g grains) and phytic acid (858 mg 100^{-1} g grains) in the untreated controls, malting of pearl millet grains with a 48 h germination reduced polyphenols and phytic acid by more than 40% (Table 8). Malting also increases vitamins such as riboflavin, thiamin, ascorbic acid, and vitamin A. There was little effect of malting on increasing the shelf-life of flour. It has been found that steeping pearl millet grains for 16 h, followed by germination for 72 h increased *in vitro* starch digestibility by 97%, protein digestibility by 17%, and total sugar by 97% (Chaturvedi and Sarojini, 1996).

Effect of malting and blanching on polyphenols, phytic acid, and fat acidity of pearl millet flour.

Treatment	Anti-nutrients (mg/100 g grain)	
	Polyphenols	Phytic acid
Untreated (control)	755	858
Malting (48 h)	449	481
Blanching	529	565
Acid treatment (24 h)	182	153

Source: Rekha (1997); Poonam (2002).

Blanching: This is one of the effective processing technologies to increase the shelf life of pearl millet. Blanching is usually done by boiling water at 98 °C in a container then submerging the grains in the boiling water (1:5 ratio of seeds to boiling water) for 30 sec and drying at 50°C for 60 min. Blanching has been observed to be effective in the retardation of enzymatic activity and thus improve the shelf life of pearl millet flour without much altering the nutrient content (Chavan and Kachare, 1994).

Blanching of seeds at 98°C for 10 sec in boiling water before milling has been reported to effectively retard the development of fat acidity in meal and enhance shelf life by 25 days (Kadlag *et al.*, 1995). Fat acidity increased about 6-fold in untreated pearl millet flour, whereas it remained almost unchanged in flour obtained from boiling water-blanched grains (98°C for 30 sec) (Chavan and Kachare, 1994). As compared to the high levels of polyphenols (755 mg 100^{-1} g grains) and phytic acid (858 mg 100^{-1} g grains) in the untreated controls, blanching of pearl millet seeds reduced the polyphenol and phytic acid contents by 28% and 38%, respectively. Also, fat acidity was reduced significantly in the case of blanched pearl millet flour as compared to raw flour after 28 days of storage (Rekha, 1997).

Acid treatment: The dark-grey grain pearl millet is highly preferred in Maharashtra state of India. Elsewhere in India and most of the world, this grain color is not preferred for food purposes. Treating the decorticated seed with mild organic acids, such as acetic, fumaric, or tartaric, and also with the extracts of natural acidic material such as tamarind (Hadimani and Malleshi, 1993) has been found to improve the product quality by reducing polyphenols and other anti-nutritional factors, thereby also increasing consumer acceptability. Various studies have reported that soaking of pearl millet in acidic solutions, like sour milk or tamarind pods, markedly reduced the color of the grain. Dehulled grains decolorized faster than whole grains because the acidic solution penetrates the grain at a faster rate (Reichert and Youngs, 1979). Among the various acidic solutions tried, dilute hydrochloric acid was more effective and suitable chemical treatment to remove pigments from whole grain before milling as compared to citric acid and acetic acid (Naikare *et al.*, 1986). Soaking grains in dilute HCl for 15 to 24 h reduces a major portion of these pigments and thus helps in the production of creamy white grains.

Soaking of pearl millet in 0.2 N HCl for 24 h reduced polyphenols by 76% and phytic acid by 82% as compared to 755 mg 100^{-1} g polyphenol and 858 mg 100^{-1} g grains of phytic acid in the untreated control (Table 8). While fat acidity of the flour during 28 days of storage increased 4-fold in the untreated control, there was very marginal increase in the flour produced from the acid-treated grains. Similar patterns of changes were observed in the acid-treated and control treatments with respect to free fatty acids and lipase activity. In another study, pearl millet grain samples given acid treatments for 6, 12, 18, and 24 h had *in vitro* protein digestibility increased by 29, 44, 56, and 59%, respectively, and the *in vitro* starch digestibility increased by 40, 57, 76, and 85%, respectively.

Changes in fat acidity (mg KOH/100 g), free fatty acids (mg/100 g fat), and lipase activity of acid and heat-treated pearl millet flour during storage.

Rancidity factor	Storage period (days)					CD ($P \leq 0.05$)
	0	7	14	21	28	
Fat acidity (mg KOH/100 g flour)						
Control	30.30	42.40	58.10	83.30	123.70	3.36
Acid treatment	35.10	35.00	36.20	38.60	38.00	1.82
Heat treatment	28.00	30.90	34.40	41.20	50.50	1.27
CD ($P \leq 0.05$)	2.56	2.17	1.26	3.65	2.56	
Free fatty acids (mg/100 g fat)						
Control	282.00	427.30	789.00	942.00	1115.00	4.32
Acid treatment	208.00	210.30	216.00	221.00	230.30	4.27
Heat treatment	67.00	70.00	75.00	80.00	84.00	5.68
CD ($P \leq 0.05$)3.82	3.94	5.99	6.82	5.20		
Lipase activity (% enzyme activity on % fat)						
Control	3.69	5.60	10.34	12.35	14.61	0.06
Acid treatment	2.90	2.93	3.01	3.08	3.21	0.06
Heat treatment	0.89	0.93	1.00	1.06	1.12	0.08
CD ($P \leq 0.05$)3.82	0.05	0.05	0.08	0.09	0.07	

Dry heat treatment: Lipase activity is the major cause of spoilage of pearl millet meal, so its inactivation before milling improves the meal quality. The application of dry heat to meal effectively retards lipase activity and minimizes lipid decomposition during storage. It has been observed that when pearl millet grains were given a dry heat treatment in a hot air oven at 100±2°C for different time periods ranging between 30 and 120 min, and then cooled to room temperature, there was about 50% increase in fat acidity, free fatty acids, and lipase activity during the 28 days of the storage of flour produced from the acid-treated grains, while there was a 4-fold increase in these parameters in the flour produced from untreated grains. Heating grains for 120 min has been found to be most effective for maximum retardation of the lipolytic decomposition of lipids during storage (Kadlag *et al.,* 1995). Fat acidity, free fatty acid presence, and lipase activity decrease significantly during storage of 28 days in pearl millet flour given an 18-h acid treatment and a 120 min heat treatment. Results also showed that heat treatment increased the shelf life of pearl millet flour as compared to raw flour (Poonam, 2002).

Parboiling: Parboiling is especially beneficial for soft-textured grains. Parboiled grains decorticate more efficiently in removing the germ and the pericarp. Parboiled-decorticated grains have slightly lower protein digestibility than the raw grains decorticated to the same extent. In practical terms, however, this detrimental effect is negligible since most traditional food processes involve cooking of flour or decorticated grains. The parboiled grains can be used for various snack food items, especially for diabetics (Sehgal *et al.,* 2004). Parboiled grains can also be cooked to produce rice-like products. In pearl millet, parboiling can prolong the shelf life of the products such as *milri*.

Alternative food products and value-addition: Processed pearl millet grains, and meals from them, are used to prepare various types of traditional and non-traditional food products. Murty and Kumar (1995) summarized and classified these into 9 major food categories (thick porridge, thin porridge, steam-cooked products, fermented breads, unfermented breads, boiled rice-like products, alcoholic beverages, non-alcoholic beverages, and snacks); and they provided the details of their preparations and the various common names in many countries. These products can be categorized under seven different types.

Traditional food products: The simplest and the most common traditional food made from pearl millet are thin porridge (gruel); thick porridge (fermented and unfermented); flat and unfermented bread such as *chapatti*. Flat, unleavened bread prepared from pearl millet flour enriched with soy flour has been reported to have high protein efficiency ratio, minimal thickness, puffing, and uniform color and texture. *Chapati* prepared from pearl millet flour produced after the grains had been bleached or acid-treated or heat-treated has been reported to have enhanced overall acceptability as compared to the *chapatti* prepared from the raw untreated grains (Poonam, 2002). Use of processed flour, in comparison to raw flour, in the product development has been found to reduce anti-nutrients and increase the digestibility (Singh, 2003).

Various types of snacks are also made from pearl millet in India. Products like *laddoo*, *namkeensev,* and *matari* have been made using blanched and malted pearl millet flour. These products were highly acceptable and have shown to have longer shelf life and stored well up to 3 months. Rekha (1997) incorporated blanched and malted pearl millet flour in various products like *bhakri*, *suhali*, *khichri*, *churma*, *shakkarpala*, *mathari* and the products were found to be organoleptically acceptable. An earlier study (Chaudhary, 1993) also indicated that the traditional products including *chapatti*, *khichri, bhakrii*, popped grain, *dalia,* and *shakkarpala* prepared from pearl millet were not only acceptable but their protein and starch digestibilities were also better.

Baked products: Pearl millet flour is not a good raw material for the baking industry, since it does not contain gluten and thus forms dough of poor consistency. For instance, cookies made from pearl millet flour do not spread during baking, have a poor top grain character, and are dense and compact (Badi *et al.,* 1976). However, pearl millet flour hydrated with water, dried, and supplemented with 0.6% unrefined soy lectin can produce cookies with spread characteristics equal to those made from soft wheat flour. Various types of biscuits and cakes produced using blanched pearl millet have been found to be organoleptically acceptable. Various types of biscuits developed by incorporating different levels of blanched as well as malted pearl millet flour have been found to be acceptable and store well up to 3 months (Singh, 2003).

Extruded products: Extrusion is being used increasingly for making ready-to-eat foods. In extrusion processes, cereals are cooked at high temperature for a short time. Starch is gelatinized and protein is denatured, which improves their digestibility. Anti-nutritional factors that are present may be inactivated.

Pearl millet grit and flour can be used to prepare ready-to-eat (RTE) products. Such products have crunchy texture and can be coated with traditional ingredients to prepare sweet or savoury snacks. Alternatively, the grits could be mixed with spices and condiments prior to extrusion to obtain RTE snacks of desirable taste. The acid-treated pearl millet yields products of better acceptability as compared to that from just decorticated pearl millet. Pearl millet, blended with soy or protein-rich ingredients, such as legumes or groundnut (peanut) cake, on extrusion gives nutritionally balanced supplementary foods (Malleshi *et al.,* 1996). Sumathi *et al.* (2007) showed that extruded pearl millet products prepared from a blend of 30% grain legume flour or 15% defatted soybean had, respectively, 14.7% and 16.0% protein, and 2.0 and 2.1 protein efficiency ratio. The shelf life of the extrudes was about 6 months in different flexible pouches under ambient storage conditions. Noodles, macaroni and pasta-like extruded products could be prepared from pearl millet flour (Desikachar, 1975). Extruded snacks prepared with mixed millet flour containing rice flour and/or corn flour and/or tapioca starch in various proportions have been shown to have acceptable appearance, color, texture, and flavor (Siwawij and Trangwacharakul, 1995). Extrusion-cooking also enhances the *in vitro* protein digestibility of foods (Malleshi *et al.,* 1996).

Utilization of pearl millet for producing soft-cooked products such as vermicelli noodles is very rare, although these grains are unique with respect to taste and aroma, and provide dietary fibre. Research at the CFTRI, has led to a process to prepare noodles (Sowbhaghya and Ali, 2001a). The noodles on cooking in water retained the texture of their strands and firmness without disintegration, and the solid loss is less than 6% (Sowbhaghya and Ali, 2001b). The noodles from pearl millet are readily acceptable in the savoury and sweet formulations.

Flakes and pops: Extensive work has been carried out on sorghum flaking at CFTRI, Mysore, and various process parameters, such as soaking time, temperature, wet-heat or dry-heat treatment conditions, have been standardized (CFTRI, 1985). The grain soaked to its equilibrium moisture content is steamed or roasted to fully gelatinize the starch, dried to about 18% moisture content, conditioned, decorticated, and then flaked immediately by passing through a pair of heavy-duty rollers. The flakes can also be used for the preparation of traditional snacks like *'uppitu'* after boiling and seasoning. The thicker flakes could be deep-fried or dry-roasted to prepare expanded crunchy snack products. Results of exploratory studies on flaking of pearl millet following the method adopted for sorghum have been promising. Pearl millet flaking would be a new avenue for its widespread utilization. Since stabilization of the oil occurs during flaking, pearl millet flakes will have longer shelf life.

Since popping involves formation of steam and development of pressure inside the grain, the optimum moisture level and popping temperature play important roles in the quality of the popped cereal. Varietal differences exist largely with respect to popping characteristics. The optimum conditions for grain popping, according to the CFTRI process, are equilibrating pearl millet to about 16% moisture and subjecting the grains to a high-temperature, short-time treatment (about 230°C for a fraction of a minute) in an air popper developed at the Institute (CFTRI 1985). The machine is highly suitable for value addition to pearl millet by popping.

Popping of pearl millet is not very popular, but the popped pearl millet is a good source of energy, fiber and carbohydrates. Varieties with hard endosperm and medium-thick pericarp exhibit superior popping quality (Hadimani *et al.,* 2001). The lipolytic enzymes are denatured during the process of popping. The nutritional advantage of the popped millet is utilized in developing formulations for supplementary foods or weaning foods for children and mothers (Bhaskaran *et al.,* 1999). Since sorghum and pearl millet are rich sources of micronutrients and phytochemicals, such products may score over similar products made from rice and wheat.

Weaning foods: Pearl millet can be successfully utilized for the development of weaning foods, as it can satisfy the nutritional requirement of infants during the crucial transitional phase of life from breast milk to other type of food, at reasonable cost. Keeping in view the delicate digestive system and nutritional requirement of the infants, malting seems to be an effective process as it provides an opportunity to develop easily digestible and nutritious weaning foods of low viscosity, low dietary bulk and of high calorie density. In addition, malting also improves the availability of protein, minerals, free sugars, vitamin B, and ascorbic acid by reducing the level of anti-nutrients and flatus producing factors. It also imparts desirable flavour and taste to the product. Blanched pearl millet can also be used for weaning foods. Blanching successfully improves the storage stability by retarding the lipolytic spoilage of meal without much altering its nutrients. Nutritive value of pearl millet based weaning foods can further be enhanced when mixed with legumes like cowpea or green gram because these pulses complement the profile of essential amino acids which is beneficial for infants' optimum growth.

Health foods: Pearl millet can find uses in preparing various types of health foods and food ingredients as it contains a relatively higher proportion of insoluble dietary fibre. This causes slow release of sugar, thus making the food products based on them especially suitable for those suffering from or prone to diabetes. For instance, various pearl millet-based food products were found to have a lower glycemic index (GI) than those based on wheat, with the extent of reduction in the GI trait ranging from 20% for biscuits to 45% for *dhokla.*

Gluten intolerance, leading to protein allergy (specifically gliadin allergy), is a physiological disorder from which about 500,000 people suffer in the USA alone (Dahlberg *et al.,* 2004). Pearl millet is gluten-free and, hence, has a good chance of being commercialized for the food-based management of this problem.

Pearl millet is rich in oil and linoleic acid accounts for 4% of the total fatty acids in this oil, giving it a higher percentage of n-3 fatty acids as compared to maize in which linoleic acid accounts for only 0.9% of the total fatty acids and, hence, is highly deficient in n-3 fatty acids. The n-3 fatty acids play an important role in many physiological functions, including platelet aggregation, cholesterol accumulation, and the immune system. Pearl millet in poultry feed can have a significant effect on the fatty acid composition of eggs and, consequently, on human health. In a poultry feeding trial, it was observed that eggs produced from layers fed a pearl millet-based diet had lower n-6 fatty acids and higher n-3 fatty acids and, thus, led to lower n-6:n-3 fatty acid ratios than those fed corn-based diets. These eggs are of special health value, especially for those prone to high levels of LDL in the cholesterol.

Health value of pearl millet-based diabetic products.

Product	Glycemic index	
	Control (wheat flour)	Pearl millet-based products
Biscuit	72.7	58.1
Chapati	69.4	48.0
Dhokla	68.4	38.0
Instant idli	69.8	52.1
Pasta	71.3	54.1

Source: Mani et al. (1993).

The bran separated as a by-product during grain processing could serve as a source of the edible oil similar to that of rice bran oil. De-oiled bran from pearl millet has lower ash and silica contents as compared to that of deoiled rice bran. Thus, it could be efficiently used as a source of dietary fibre. Pearl millet bran contains a high proportion of soluble dietary fibre and could be tapped for hypocholesterolemic and hypoglycemic effects. In view of this, fibre-regulated pearl millet flakes could be an ideal snack for the obese and for calorie-conscious people (Hadimani and Malleshi, 1993).

Cereal grains and egg composition of n-6 and n-3 fatty acids.

Fatty acid	Diet		
	Corn	Corn + pearl millet	Pearl millet
Diet composition of fatty acid (% of total fatty acids)			
Total n-6	59.3	47.0	40.0
Total n-3	2.4	2.5	3.3
n-6 : n-3 ratio	25.2	19.0	12.8
Egg composition of fatty acid (mg/g yolk)			
Total n-6	66.8	55.6	47.3
Total n-3	5.1	5.5	5.7
n-6 : n-3 ratio	13.1	10.1	8.3

Modified from Collins *et al.* (1997).

Drinks: Pearl millet flour is used in making different types of drinks. A fermented drink known as *rab/rabari* is consumed widely during summer months in Rajasthan. Similarly, traditional drink called as 'Cumbu Cool' is consumed in Tamil Nadu. The National Dairy Research Institute, Karnal has recently developed and launched pearl millet '*lassi*' made from pearl millet flour.

Opportunities for commercialization

One of the greatest constraints in the commercialization of pearl millet grain for food purposes has been a misplaced social stigma dubbing these as poor men's crop primarily because it is grown in marginal environments, where poverty is common. Thus, pearl millet could not make it to the food basket of the urban elite whose consumption choices play a dominant role in the commercialization of any food product.

Grain quality and nutritional studies now show that pearl millet grains are more appropriate choices for the nutritional security of the rural and urban poor who have limited access to other sources of dietary components. In addition, pearl millet grains could also be more appropriate choice than the fine cereals such as wheat and rice for the elite who will benefit from their high nutraceutical properties. This will require different approaches to commercialize pearl millet to serve these widely different consumer classes.

Policy support from the governments plays a significant role in product and process commercialization, at least in the initial stages when the food products from grains of new crop species have to compete with those from the established crop species. For instance, subsidy on wheat and rice production almost all over the world plays a big role in their production and marketing. On top of this, is the subsidized procurement and supply of wheat and rice through the Public Distribution system in India. Similar support is not available to pearl millet. This leaves farmers with little incentive for investment in production as the returns are not economical when increased production leads to a drop in grain prices. The low-resource agriculture, characterized by rain-fed cultivation of pearl millet crops with negligible external inputs, leads to low productivity with large variation in production and grain surpluses across the years. The low volume and inconsistency in grain supplies reduce the dependability of producers for grain supplies, which is so essential for commercialization. Opportunities exist to drastically reduce or even eliminate these uncertainties through governmental policy support for increased and stable production and marketing of pearl millet grain surpluses.

Most of those involved in commercial grain processing and food manufacturing are not familiar with the possible alternative food uses and health value of pearl millet. Commercialization of pearl millet grains for alternative and health food uses needs to be viewed in a broader context from production to utilization, and emerging challenges and opportunities.

2.10 Major problems associated storage of grains

Lesser grain borer (*Rhizopertha dominica*), rust-red flour beetle (*Tribolium castaneum*) and khapra beetle (*Trogoderma granarium*) are the major stored grain pests of pearl millet. The damage leads to both quantitative and qualitative losses. These pests of stored grains have a high rate of multiplication, destroy large quantities of grain and contaminate the rest with excreta and undesirable odors.

Control measures: Experiments conducted under the AICPMIP to evaluate its control measure, found that deltamethrin @ 0.05% spray on gunny bags showed significantly less damage by lesser grain borer (*R. dominica*).

An experiment on eco-friendly management *R. dominica* is under progress, in which seed dressing with neem leaf powder @10 g/kg seed was found effective showing 85.67% seed viability as compared to 49% seed viability in untreated.

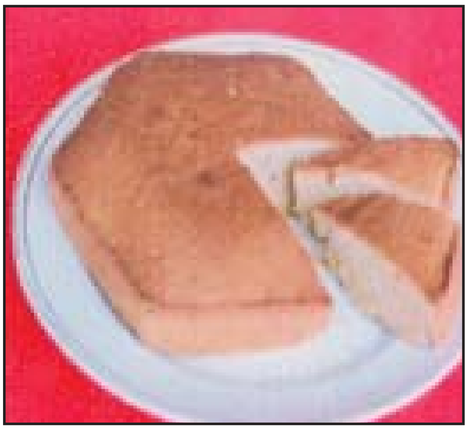
2.11 Researchable issues

- Development of varieties/hybrids of pearl millet with better regenerative capacity on reversal of dry spell for harsh environment/drought prone areas.
- Development of hybrids/varieties resistant/ tolerant to salt/high temperature.
- Problem of seed setting in pearl millet in Haryana.
- Shift in focus of breeding from productivity improvement to identification of end product specific traits.
- Bio-fortification in pearl millet for iron & zinc.
- Enhancement of shelf life of pearl millet.
- Generating authentic data on nutritional benefits of pearl millet.
- A study on demand survey for pearl millet.

Value added products of Pearl millet (Bajra)

Bread

Chocolate Doughnuts



Walnut Cake

Eggless Cup Cakes

Chocolate Cake

Macronies

Eggless Cake

Muffines

Cookies

Biscuit

Noodles

Pasta

Value added products of Pearl millet (Bajra)


Porridges


Roti


Batti


Khichri


Ladoo


Shakkerpara


Churma


Mathri


Nankhatai


Buns


Stuffed Roll


Rolls

Finger millet
(Ragi)

3. FINGER MILLET (*Eleusine coracana* (L.) Gaertn.)

3.1 Introduction

According to DeCondolle (1886) mandua probably originated in India, as many of the forms exist in the country. It might have originated from *Eleusine indica*, a grass that occurs in many parts of northern India. It is supposed to have spread from India to Abyssinai and rest of Africa (Vaviliv, 1951), Mehra (1962) considers *Eleusine coracana* to be of African origin.

The archaeological findings on the origin of finger millet was from Ethiopia it dates back to about the third millennium BC (Hilu *et.al* 1979). The two distinct races of finger millet recognized are the African highlands race and Afro-asiatic lowland race. The African highlands race is considered to be derived from *E. africana* under cultivation and this gave rise to the African lowland race which later migrated to India and developed as the Afro-Asiatic lowland race (Mehra, 1962; Purseglove, 1976). This migration of finger millet to the Indian sub-continent is likely to have occurred around 3000 BC. Studies on the patterns of variability in African and Asian finger millets has by and large indicated relatively larger diversity in African germplasm compared to Indian collections, lending support to the view that Africa could be the primary centre of origin. The long history of cultivation in the Indian subcontinent for more than 5000 years. Since then, accompanied by human selection, has resulted in the generation of large diversity in landraces and local cultivars in India. Close study of various characters in Indian germplasm has revealed that for economically important characters such as finger length, finger width, finger number, grain yield, ear weight, total biomass and leaf number, the Indian germplasm possesses large variability indicating India as the secondary centre of diversity (Naik *et. al*, 1993).

Mandua or finger millet is widely cultivated in India, Africa, Ceylon, Malaysia, China and Japan. It is an important staple food & fodder crop in many parts of eastern and southern Africa, as well as in South Asia.

In India, it is widely grown from Kanyakumari in South to Himalayan region in the North, Gujarat in the West and Sikkim, Odisha and West Bengal in East mostly by resource poor formers, tribal, hilly/ remote areas. The crop has wider adaptability to different soils from poor to high fertile soils. It can also tolerate certain degree of alkalinity. The most suitable soils are alluvial, loamy and sandy soils with good drainage.

In India, it is cultivated over an area of 1.30 million hectares with total production of about 2.04 million tonnes. It is an important crop of Karnataka with > 60% area of the country followed by Uttarakhand (10%), Maharashtra (9.6%), Tamilnadu (6.5%), Odisha (4.8%) and Andhra Pradesh (3.6%). It is mainly a *Kharif* crop, but also grown during *Rabi*/summer in Karnataka and Odisha over a smaller area.

Millets are the most important cereals of the semi-arid zones of the world. For millions of people in Africa and Asia they are staple food crops. Among millet crops, finger millet figures prominently; it ranks fourth in importance after sorghum, pearl millet and foxtail millet. Finger millet cultivation is more widespread in terms of its geographical adaptation compared to other millets. It has the ability to withstand varied conditions of heat, drought, humidity and tropical weather. In general all small millets are C4 plants with high photosynthetic efficiency. They have good drought withstanding and evading ability. Finger millet has good ability to rejuvenate after alleviation from stress, while other small millets are short duration crops and therefore are suitable for contingency cropping.

The cultivated *E. coracana* is a tetraploid (2n=4X=36) and exhibits morphological similarity to both *E. indica* (2n=18) and *E. Africana* (2n=36). It was earlier thought that cultivated *E. coracana* originated from *E. indica*, of which the distribution is quite wide, from Africa eastwards to Java. The cytological evidence indicates that *E. indica* has contributed one of the genomes (AA) to the cultivated *E. coracana* (AABB) which is an allotetraploid. The species *E. africana* (2n=36), which is also a tetraploid, exhibits great similarity in morphological feature with *E. coracana;* they are genetically related and gene flow occurs between them in nature, suggesting *E. coracana* possibly originated from *E. africana* through selection and further mutation towards larger grains (Channaveeraiah and Hiremath, 1974; Hilu and de Wet, 1976).

Vernacular Names:

ENGLIGH	:	African millet, finger millet
Sudan	:	*Telebun*, *tailabon* (*Ar*)
Kenya	:	*mwimbi*, *mwimti*, *ulezi* (*Swa*)
Tanzania	:	*mwimbi*, *ulezi* (*Swa*)
Malawi	:	*mawere*, *lipoko* (*Ch*), *usanje* (*Y*), *khakwe* (*Ngu*), *mulimbi* (*Se*) *Rupoko* (*Tu*), *maleshi* (*Tu/Nk Su*), *mawe* (*To*)
Zimbabwe	:	*rapoko, zviyo. Njera, rukweza* (*c*), *mazhovole*, *uphoko* (*Nd*), *poho* (*H*)
Zambia	:	*Kambale*, *lupoko*, *mawele*, *majolothi* (*Ny*) *amale*, *blue* (*B*)
Uganda	:	bulo
Ethiopia	:	*dagussa* (*Am*/*Sodo*), *tokuso* (*Am*), *barankiya* (*o*)

INDIA

Hindi	:	*ragi*, *mandika*, *marawah*, *mandua*
Bengali	:	*marwa*
Oriya	:	*mandiya*
Telugu	:	*ragi*, *chodi*
Tamil	:	*Keppai*, *ragi*, *kelvaragu*
Malyalam	:	*mathuri*, *ragi*
Kannand	:	*ragi*
Marathi	:	*nagli*, *nachani*
Gujarati	:	*nagli*, *bavto*
Punjabi	:	*jandhuka*, *mandhal*

ORIGIN/ECOLOGY

Origin	:	Ethiopian region of Africa
Existential	:	Across the States in India. A famine crop in Ethiopia, staple food in the regions of perturbed ecology across the globe, beverages, baby food, cattle fodder & thatching.
Ecology	:	A warm season crop grown from sea level to 3000 metres (msl.), C4 Plant
Soils	:	Grows well on free draining soils with steady supply of moisture where other cereals do not grow.
Rainfall	:	500 – 2000 mm.
Water needs	:	350-400 mm.
Irrigation schedule	:	IW/CPE ratio 0.6, Flowering & maturity are stages for irrigation.
Temperature	:	Optimum 15 – 27° C.

Species: *E. Coracana Coracana Elongata* (three sub-races are recognized: *laxa, reclusa* and *sparsa*) Long slender inflorescence, branches 10-24 cm long, digitately arranged spikes spreading and curved outward at maturity. *Plana* (three sub-races are recognized: *seriata, confundere* and *grandigluma*) Large spikelet (8-15 mm long) arranged in two more or less even rows long the rachis giving the inflorescence branch a flat ribbonlike appearance. *Compacta* Spikelets are composed of 9 or more florets and incurved at the tip to form a large fist-like inflorescence. *Vulgaris* (has four subraces; *liliaceae, stellata, incurvata* and *digitata* are recognized based on minor differences) Most common type with 4-8 florets in a spikelet giving an appearance of semi-compactness with tip of finger incurved at maturity.

Morphology: Mandua is an erect, tufted annual, growing to 60 to 122 cm in height. Root system of mandua plant consists of a large number of slender and fibrous roots which are able to absorb moisture very thoroughly and efficiently from the soil. Mandua plant tillers profusely. The stem is compressed with fringe of hairs. The tillers bear at the end of the culm earheads which consists of a whorl of finger like spikes (two to eight in number) in which spikelet are arranged closely on both sides of a slender rachis. The spikelet's are crowded into two overlapping rows on the outer sides of the spike. Each spikelet contains four to five flowers. The spikes may take six to eight days to complete flowering. Flowering takes place simultaneously in all fingers. Crop is generally self-fertilised. The spikelets contain three to eight seeds which are very small in size and generally redish-brown in colour.

Nutritive value: The crop is valued for its nutritious grains with high calcium and fibre content and sweet smelling straw liked by cattle. It is grown both for grain and straw. In northern hills, grains are eaten mostly in the form of çhapaties'. In south India grains are used in many preparations like cakes, puddings, sweets, etc. Germinating grains are malted and fed to infants also. It is also good for pregnant women. It is a nutritive food for adults of different ages. The grain of finger millet has a fine aroma when cooked or roasted and is known to have many health-promoting qualities. The grain can be stored for years without insect damage, which makes it a particularly valuable crop for famine-prone areas. The crop provides food grain as well as straw which is valued animal feed, especially in the rainfed areas. Among the major food grains, finger millet is one of the most nutritious crops for protein, minerals (calcium and iron) and amino acids (methionine, an amino acid lacking in the diets of hundreds of millions of the poor who live on starchy foods such as cassava, plantain, polished rice, and maize meal); and provides 8-10 times more calcium than wheat or rice. **Finger millet carbohydrates are reported to have the unique property of slower digestibility**. The excellent malting qualities have added to the uniqueness of the grain in expanding its utility range in food processing and value addition. **It is good for persons suffering from diabetes.** The green straw is suitable for making silage, which is sweet smelling and consumed by cattle without any wastage.

Important Food and Industrial uses of finger millet

Millets	Food products	Industrial products
Finger millet	*Roti*, dumpling, popped millet, malt-food.	Malting/brewing, baby foods, bakery and food for diabetics.

Table 22 : Chemical composition & nutritive value of Fodder (on % dry basis).

Crop	Stage/Type of forage	Crude Protein	Ether Extract	Crude fibre	Digestible Crude Protein	Total Digestible nutrients
Finger millet	Dough stage	9.4	2.1	28.8	5.5	61.6
	Silage	3.6	1.5	38.8	2.8	-
	Straw	3.4	1.3	37.2	0.4	56.0

3.2 Comparative analysis

State-wise area, production and yield estimates of finger millet is given in Table-23.

Table-23 : State-wise Normal Area, Production and Yield of Finger millet (Average of 2007- 08 to 2011-12)

States	Season	Area ('000'ha)	Production ('000' tonnes)	Yield (Kg/ha)
Andhra Pradesh	Kharif	46.8 (3.6)	52.8 (2.6)	1128
Bihar	Kharif	10.6 (0.8)	8.6 (0.4)	811
Chhattisgarh	Kharif	8.5 (0.7)	2.3 (0.1)	269
Gujarat	Kharif	18.2(1.4)	15.2 (0.7)	835
Jharkhand	Kharif	11.3 (0.9)	6.5 (0.3)	577
Kanataka	All seasons	781.4 (60.1)	1412.6 (69.2)	1808
Maharashtra	Kharif	124.8 (9.6)	122.6 (6.0)	982
Odisha	Kharif	62.7(4.8)	40.7(2.0)	648
Tamil Nadu	Kharif	84.9(6.5)	180.9(8.9)	2130
Uttarakhand	Kharif	129.6(10.0)	175.9 (8.6)	1357
West Bengal	Kharif	11.5(0.9)	13.1 (0.6)	1138
Others	Kharif	9.4(0.7)	9.5 (0.5)	1011
All India	**-**	**1299.7**	**2040.7**	**1570**

NB: Figures in parenthesis indicates % share to All India.
Source: Directorate of Economics & Statistics, DAC, GOI.

Tamil Nadu state has recorded highest productivity (2130 Kg/ha) of finger millet followed by Karnataka (1808 Kg/ha) which is above the National Average Yield (1570 Kg/ha). The list of potential districts of finger millet is given in **Table-24**.

Table-24: List of potential districts of finger millet

States	District with an average area of 2,000 ha and above under finger millet in descending order
Andhra Pradesh	Vishakhapattnam, Chittoor, Vizianagaram, Anantpur, Mahboobnagar and Srikakulam (**6 districts**).
Bihar	Madhubani (**1 district**)
Gujarat	Dang and Valsad (**2 districts**).
Jharkhand	Ranchi (**1 district**)
Karnataka	***Kharif:*** Tumkur, Ramnagar, Mandya, Kolar, Hassan, Chitradurga, Chickmaglur, Mysore, Bengaluru (R), Chickballapur, Bengaluru (U), Davangere, Chamrajnagar and Bellary (**14 districts**).
	Rabi: Hassan, Mysore and Mandya (**3 districts**)
	Summer: Mandya, Chitradurga and Tumkur districts with about 1000 ha and above during summer (**3 districts**).

Maharashtra	Nasik, Kolhapur, Ratnagiri, Thane, Raigarh, Pune and Sataraur (7 **districts**).
Orissa	Koraput, Ganjam, Rayagada, Gajpati, Malkangiri, Nowrangpur, Kalahandi, Nawapara and Bolangiri (**9 districts**)
Tamilnadu Uttrakhand	Krishnagiri, Dharmapuri, Salem, Erode, Vellore and Thiruvannammalai (**6 districts**). Almora, Pauri Garhwal, Tehri Garhwal, Chamoli, Pithoragarh, Bageshwar, Champawat, Uttar Kashi and Nainital (**9 districts**)
West Bengal	Darjeeling (**1 district**)

3.3 Varietal development

The improved varieties developed and released as Central/State variety during last 15 years (1995-2010) are listed below:-

Bhairabi, Bharti, Birsa Marua-2, Champavathi, Chilka, Co (Ra)-14, KM-65, L-5, Maruthi, MR-1, MR-2, MR-6, ML-365, GPU-26, GPU-28, GPU-45, GPU-48, GPU-67, Paiyur (Ra)-2, Saura, KMR-301 and VL Ragi-146.

So far no hybrid has been developed, however, source of male sterile lines have been identified in finger millet, which are now being transferred in to the background of potential varieties like GPU-28, GPU-67, RAU-8, CO (Ra)-14, and Paiyur-2 for development of finger millet hybrids. Karnataka is the major finger millet growing States. About a dozen new varieties have been released for Karnataka during last 15 years. The status of State-wise varieties released and popular varieties is given in **Table-25.**

Table-25: State-wise varieties released and popular varieties of finger millet

State	**Season**	**Varieties released/ recommended during last 15 years**	**Varieties popular in the State**
Andhra Pradesh	Kharif	Padmawathi, Maruti, Bhairabi, Champavathi, Chilika, Bharathi & Shri Chaitanya.	Padmawathi, Maruti, Kalyani, Godawari, AKP-2, SURAJ, Simhadri, Ratnagiri, Gouthami, Sapthagiri.
	Rabi	Bhairabi, Bharathi & Maruti.	
Bihar	Kharif	Birsa Marua-2	BR-407.
Chhattisgarh	Kharif	Bhairabi, Chilika, GPU-67 & Saura.	VL-149, PR-202, Ratnagiri, GPU-28, HR-374 & VL-147.
Gujarat	Kharif	Chilika, GPU-45 & Saura.	Gujarat Nagali-2 & Gujarat Nagali-3.
Jharkhand	Kharif	Birsa Marua-2, GPU-45 & GPU-67.	-
Karnataka	Kharif	VL Ragi-146, Akshaya, Champavathi, GPU-28, MR-1, Bhairabi, GPU-26, GPU-45, GPU-48, L-5, Divya (MR-6), Rathana, ML-365, KMR-301 & GPU-67.	Indaf-8, Indaf-9, HR-911, PR-202, MR-1, MR-6, L-5, GPU-26, GPU-28, GPU-66, GPU-45, VR-708 & OEB-10.
	Rabi/ Summer	Bhairabi, GPU-28, GPU-26, KMR-301 & ML-365.	Indaf-5, Indaf-7, Indaf-15 & Indaf-9, HR-911, GPU-26 & GPU-48.

State	Season	Varieties released/ recommended during last 15 years	Varieties popular in the State
Madhya Pradesh	Kharif	Bhairbi & Chilika.	Chilika & GPU-45.
Maharastra	Kharif	Bhairabi, GPU-45 & GPU-67.	-
	Rabi	Bhairabi.	-
Orissa	Kharif	Subra, Chilika & Saura.	-
	Summer	Subra.	-
Tamilnadu	Kharif	Champavathi, Chilika, Co(Ra)-14, Paiyur (Ra)-2 & GPU-67	GPU-28, CO-7, CO-10, CO-11, CO-12, CO-13, CO-14, Paiyur (Ra)-2, K-567, Indaf-5, Indaf-7, Indaf-9, Paiyur-1, PR-202 and TRY-1.
Uttar Pradesh	Kharif	KM-65 & Champavathi	-
Uttrakhand	Kharif	KM-65, Champavathi, VL Mandua-315, VL Mandua-324, PRM-1 & GPU-67.	VL-146, VL-149, VL-315, VL-324, PRM-1 & PRM-2.

Yield potential and gap: Improved varieties with yield potential of more than 4 tonnes/ha (L-5 & GPU-28) and > 5 tonnes/ha (ML-365 and MR-6) have been developed in finger millet. However, improved varieties, except GPU-28 in Karnataka, are not reaching to the farmers for want of availability of seed of these new varieties.

FLDs have been organized by the All India Coordinated Small Millets Improved Project, Bengaluru over an area of 973.32 ha during 2007-08 to 2012-13 through its centres located in Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Maharashtra, Odisha, Tamil Nadu, Uttar Pradesh, Uttarakhand and Union Territory of Puducherry on improved package of practices including value addition. The state wise progress of FLDs of finger millet is given in **Table-26**.

Table-26: The state wise progress of FLDs of grain Finger millet

Sl. No.	State	Year wise area (ha) under FLD					
		07-08	09-10	10-11	11-12	12-13	Total
1	Andhra Pradesh	41.40	-	10.00	10.40	10.60	72.40
2	Chhattisgarh	-	-	2.00	8.80	31.20	42.00
3	Bihar	10.00	-	10.00	-	-	20.00
4	Gujarat	-			2.00	10.00	12.00
4	Jharkhand	17.50	-	14.20	32.12	-	63.82
5	Karnataka	148.90	35.00	144.40	93.30	38.08	459.68
6	Maharashtra	28.00	13.60	17.00	18.00	20.00	96.60
7	Odisha	10.40	-	22.24	30.70	10.00	73.34
8	Puducherry	-	-	1.00	1.00	-	2.00
9	Tamil Nadu	30.00	4.00	10.00	20.00	10.00	74.00
10	Uttarakhand	10.60	7.70	8.28	8.36	20.04	54.98
11	Uttar Pradesh	-	2.50	-	-	-	2.50
	Total	**296.80**	**62.8**	**239.12**	**224.68**	**149.92**	**973.32**

The State-wise performance of FLDs of finger millet is given in **Table-27.**

Table-27: Yield performance of FLDs of Finger millet

Sl. No.	State	Plot	Year wise yield in Kg/ha					
			07-08	09-10	10-11	11-12	12-13	Mean
1	Andhra Pradesh	FLD	1947	-	1690	1842	1749	1807
		Control	1238	-	1323	1581	1280	1356
		SAY	1255	-	1190	952	1098	1124
		% Yield gap over					**Control**	33
							SAY	61
2	Chhattisgarh	FLD	1569	-	2490	1991	1981	2008
		Control	519	-	600	609	558	572
		SAY	280	-	276	247	280	271
		% Yield gap over					**Control**	251
							SAY	641
3	Gujarat	FLD	-	-	-	1615	1937	1776
		Control	-	-	-	1307	1157	1232
		SAY	-	-	-	813	929	871
		% Yield gap over					**Control**	44
							SAY	104
4	Jharkhand	FLD	-	-	2538	2495	-	2517
		Control	-	-	2175	2066	-	2121
		SAY	-	-	522	662	-	592
		% Yield gap over					**Control**	19
							SAY	325
5	Karnataka	FLD	2627	2747	2661	2061	1372	2294
		Control	2040	2008	1597	1474	1043	1632
		SAY	1797	1715	2015	1871	1543	1788
		% Yield gap over					**Control**	41
							SAY	28
6	Maharashtra	FLD	1388	1770	1894	1615	2033	1740
		Control	930	1143	1423	1168	1562	1245
		SAY	969	908	975	1062	1120	1007
		% Yield gap over					**Control**	40
							SAY	73
7	Odisha	FLD	1930	-	1810	2800	2290	2208
		Control	1240	-	1020	1320	940	1130
		SAY	692	-	709	562	770	683
		% Yield gap over					**Control**	95
							SAY	223
8	Tamil Nadu	FLD	3112	1291	2399	2425	1798	2205
		Control	2048	1089	1853	2029	1410	1686
		SAY	1877	1976	2260	2715	2164	2198
		% Yield gap over					**Control**	31
							SAY	At par
9	Uttarakhand	FLD	1496	1590	1707	1700	1653	1629
		Control	930	986	1049	1100	1163	1046
		SAY	1398	1235	1331	1392	1384	1348
		% Yield gap over					**Control**	56
							SAY	21
10	Uttar Pradesh	FLD	-	816	-	-	-	816
		Control	-	592	-	-	-	592
		SAY	-	1333	-	-	-	1333
		% Yield gap over					**Control**	38
							SAY	-39

The yield performance given above in FLD indicates largest yield gap over State Average Yield in Chhattisgarh (641%) followed by Jharkhand (325%), Odisha (223%), Gujarat (104%), Maharashtra (73%), Andhra Pradesh (61%), Karnataka (28%) and Tamil Nadu (0.3%).

3.4 Climatic requirement

Mandua is a crop of tropical and subtropical climate and can be grown successfully from sea level to an altitude of 2100 metres on hill slopes as well as in plains. It is very a hardy crop. It is grown in areas having annual average rainfall between 50 to 100 centimetre. In regions of higher rainfall it can be raised on well drained soils as a transplanted crop. It can be grown under rainfed as well as irrigated conditions.

Requirement of temperature for different critical stages of finger millet:

A. Temperature:

a. Finger millet is a thermo-insensitive crop.

b. Optimum temperature: 27 to 32^{0}C and 22^{0}C Day and night temperature, respectively.

c. Critical temperature: 18 to 32^{0}C. Night temperature below 18^{0}C and day temperature above 32^{0}C inhibit flowering

B. Photo-period:

a. It is a quantitative short day plant

b. Optimum photoperiod is 10 h day length

c. Critical photoperiod: 8.5 – 11 h (Above and below which flowering ceases)

C. Soil pH:

a. Optimum : 6.5-6.8

b. Critical : 5.5 to 8.5

Impact of rise in temperature on yield of the crop

Literature shows that in finger millet an increased temperature more than 36^{o}C or 38^{o}C found to decrease the grain yield drastically compared at 32^{o}C. Most sensitive stages are booting, panicle emergence and flowering. High temperature during these stages decreases panicle emergence, number of grains per panicle, harvest index and thus grain yield.

Climate resilience of the crop

Finger millet has good ability to rejuvenate after alleviation from stress, while other small millets are short duration crops and therefore are suitable for contingency cropping.

3.5 Genetic potentiality advancement

It is now evident that cultivated finger millet is highly variable within its primary centre of origin in Africa and secondary centre in Indian sub-continent. Both wild finger millet (*Eleusine coracana* subspecies *africana*) and the cultivated finger millet (*Eleusine coracana* subspecies *coracana*) are important from the point of view of germplasm collection and conservation and form the primary genepool. Wild finger millet (subspecies *africana*) is native to Africa but has migrated to several warmer parts of Asia and America. Natural hybridization between wild and cultivated finger millets has resulted in hybrid derivatives and in companion weeds of the crop in Africa. This no doubt has led to the generation of new diversity of intermediate forms. The weedy and wild forms are restricted to the closely related annual species. For the sake of taxonomic interest, the cultivated finger millets have been divided into four races and several sub-races, which are mainly based on the inflorescence morphology (Prasada Rao *et.al*, 1993). The diploid wild species *E. indica, E. floccifolia* and *E. tristachya* form the secondary genepool and the tertiary genepool comprises species *E. intermedia, E. gaegeri, E. kigeziensis, E. multiflora* and *E. semisterlis (E. compressa*). Finger millet variety GPU 28 has been well received by the farmers and made significant impact on productivity.

Status and scope for transgenic and genomics

Crop improvement is mainly through conventional plant breeding based on selection and hybridization. Application of genomics has potential to improve productivity, quality and resistance to biotic and abiotic stresses. However, there is limited scope for the use of transgenics in finger millet.

Status and scope of bio-fortification in respect of iron, zinc and calcium in the grains

Finger millet is rich in micronutrients viz., calcium, iron, zinc and nutraceuticular parameters like polyphenols, phytic acid, FRS activity, dietary fibre, non-starchy carbohydrate compared to staple food crops, rice and wheat and hence are highly valuable for bio-fortification.

Reasons for non adoption of new hybrids / varieties by the states / farmers if any.

1. Lack of knowledge on high yielding varieties
2. Non availability of quality seed (absence of seed chain).
3. Low seed replacement rate
4. Poor socio economic conditions of farmer

Impact of crop with respect to uptake of nutrients, soil health and underground water

Finger millet is eco friendly crop, good for organic agriculture and requires less nutrients as compared to many other cereals. They are nitro positive and require 30 to 50 kg nitrogen per ha along with 20 – 40 kg phosphoric fertilizer.

Possible alternative crops and varieties in the events of natural calamities like drought & flood.

Small millets are short duration crops. Proso millet is the earliest among small millets maturing in 60 – 70 days and other small millets *viz*., foxtail, little and barnyard millets mature in 75 – 85 days whereas kodo and finger millets mature in 100-130 days. Because of their earliness, low water requirement and high drought tolerance these crops fit very well in contingency crop planning to mitigate drought. When favorable conditions return after alleviation of stress the small millets especially finger millet recuperate fast and grow luxuriantly.

3.6 Recommended package of practices:

Recommended package of practices by ICAR

Sl.No.	Operation	Finger millet
1. Time of Sowing		
1.1	Kharif	April-May – UP, HP & parts of Karnataka June-July – Karnataka, TN & AP June – Maharashtra, Odisha, Bihar, Uttrakhand, MP & Gujarat
1.2	Rabi	Sept-Oct – Karnataka, TN & AP
1.3	Summer	Jan-Feb – Karnataka, TN, AP & Bihar
2. Method of sowing		
2.1	Manual (%)	100
2.2	Mechanized (%)	Nil
3. Seeds		
3.1	Seed Rate	10 kg/ha
3.2	Row to row and Plant to plant distance	22.5 - 30 cm / 7.5 to 10 cm
3.3	Ideal plant population/ha	4-5 Lakh per ha
3.4	Seed treatment	
	Fungicides (Names & Dose)	Carbendazim @ $2gkg^{-1}$ or *P. flourescens* @ $6gkg^{-1}$
	Bio-fertilizer (Name & Dose)	*Azospirillum brasilense and Aspergillus awamouri* (PSB) @ 25 g/kg seed

Sl.No.	Operation	Finger millet
		4. Fertilizer doses
4.1	Kharif (Rainfed)	
	Urea	74 kg/ha
	DAP	87 kg/ha
	SSP	250 kg/ha
	MOP	42 kg/ha
	Micro-nutrient	*ZnSo4 (12.5 kg /ha), Borax - 5 kg / ha
	Bio-fertilizers	*Azospirillum brasilense and Aspergillus awamouri @25 g/kg seed*
	Manures	7.5 t FYM/ha
4.2	Rabi/Summer (irrigated)	
	Urea	176 kg
	DAP	109
	SSP	312
	MOP	83
	Micro-nutrient	*ZnSo4 (12.5 kg/ha), Borax (5 kg/ha)
	Bio-fertilizers	Az. bras & Asp. awamouri
	Manures	7.5 t FYM/ha
		5. Weeds Control
5.1	Name of major weeds	**Monocots** – *Digitaria marginata, Cynodon dactylon, Cyp. rotundus, Setaria glauca, Crommelina bengalensis* etc.**Dicots** – *Euphorbia hirta, Leucas aspera, Acanthospermum hispidum Phylanthus niruri, Amaranthus viridis* etc.
5.2	Control Measures	2 Inter culture + 1-2 Hand weeding
5.3	Weedicides (name, dose and time of application)	Isoproturon (0.5 ai/ha)- Pre-emergent (rainfed / drilled2,4D(0.75 kg ai/ha) – Post emergent (15-20 DAS)Oxyflorofen @ 0.1 lit a.i. / ha, pre-emergent (Transplanted / irrigated)
		6. Disease/Pest Management
6.1	Major pests	Defoliators, sucking pests and ear head worms
6.2	Major diseases	Blast, Brown spot and Foot rot
6.3	Control measures for pest	Incidence levels are less hence no insecticides are recommended, recommended varieties have inherent tolerance
6.4	Name of fungicides	1.Carbendazim @ 0.5g/lit or Edifenphos 1ml/lit, or Saaf 2g/lit or *P. flourescens* 4g/ l2. Need based spray of mancozeb 0.2%
6.5	IPM	1.Growing blast resistant varieties like GPU 28, GPU 48, L5 & VL 149 etc.2. Need based spraying of fungicides or bioagents.3. Application of value added bioagents like T. v. or P. f. @ 1 kg in 25 kg FYM at weeding
		7. Harvesting & Threshing
7.1	Time	
	Kharif	Nov-December
	Rabi/Summer	Jan-February/April-May
7.2	Method(Harvesting)	
	Manual (%)	100
	Combined (%)	-
7.3	Thrashing	
	Manual (%)	75
	Thrashers (%)	25

3.7 Cropping System

Finger millet: It is commonly grown both as sole crop as well as mixed crop with pulses and oil seeds. It is also grown in rotation with pulses.

Improved inter cropping systems: Finger millet + pigeon pea in 8-10 : 2 or finger millet + field bean in 8: 1 for Karnataka and Tamil Nadu and finger millet + field bean in 6 : 2 row proportion for Bihar. Finger millet + soybean (90:10 crop mixtures) for Gadhwal region of Uttarakhand. Finger millet + moth bean / black gram (4:1) for Kolhapur.

Rotations / sequence cropping: Rotation with legumes like green gram/ black gram. Rice bean/ soybean for Northern regions and horse gram/pigeon pea /ground nut for Southern states.

3.8 Crop products

Finger millet is normally consumed in the form of flour-based foods such as roti (unleavened pancake), mudde (stiff porridge/dumpling) and ambli (thin porridge). Idly and dosa which are conventionally prepared from rice can also be prepared using the millet as base. Finger millet are also use for preparation of noodles, papads and popping. Finger millet could be decorticated to prepare ready-to-cook grain i.e. ragi rice.

In rural India, many kinds of traditional foods are made and form staple diet for many households. Ragi is eaten in the form of mudde (dumpling or stiff porridge) and / or roti. Many other traditional foods are made from popped ragi flour mixed with sugar/jaggery/ghee/milk/butter milk and salt. In several rural households, a vast variety of traditional snacks are made from ragi and other small millets.

The millet grains offer many opportunities of diversified utilization and in adding value. With proper processing, it is possible to make different kinds of food products by adopting appropriate milling, propping and other technologies.

Finger millet flour is easy to make since the endosperm and bran are pulverized freely and such, flour fibre content is normally higher. However, it is possible to reduce fibre content by adopting simple sieving methods.

Malting of ragi for food uses is in practice from time immemorial in southern India. Ragi has superior malting properties compared to other cereal grains like rice, jowar and bajra. Ragi contains high level of calcium and its protein is rich in methionine, a sulphur containing amino acid. Finger millet malt has acceptable taste, very good aroma and shelf life.

Preparation of Ragi malt: Well cleaned good quality ragi having germination should be used for the preparation of malt. The grain should be first washed in water then, steep (soak the grains) in clean soft water in a vessel of appropriate size for a period of 18-24 hrs. change the water twice or thrice. After soaking for a required period, the grains are taken out and again washed. After draining the excess water, the grains are spread over a gunny bag or thick cloth, spread thinly and allowed for germination for 36-48 hrs, depending upon the temperature and humidity prevailing. It is desirable to another cloth so as it facilitate uniform germination. During germination, water should be sprinkled as and when necessary to keep the sprouts moist. Two days of germination period is sufficient for ragi. If germination is allowed too long, it will trigger root and shoot growth and enzymes that promote digestion of food develops. Important among them are starch, protein and fat digesting enzymes. In finger millet, starch content is more and amylase is the most important enzyme produced.

After required period of germination, the grains are dried in open sun by spreading thinly on a cloth. 6-8 hrs of sun drying should be sufficient. Soon after drying, the root lets are removed by rubbing grains gently against dry clean cloth. The separated root lets are aspirated leaving malted ragi.

Malted ragi should be mildly toasted or kilned at 65-70°C in an iron pan, heated at low flame. Malting enhances carbohydrate and protein digestibility and in addition, the water soluble vitamins is also enhanced along with increase in the bio-available minerals and other nutrients. The roasted grains is ground into fine flour and sieved through an 80 to 100 micron sieve mesh or through a muslin cloth. The malt so obtained has improved nutritional quality, enhanced digestive enzymes and is an ideal base to prepare weaning foods, infant foods, malted milk food, health foods, medical foods etc., The Central Food and Technological Research Institute (CFTRI), Mysore has developed ragi malt based weaning food formulation.

Fermented beverage: Finger millet malt is fermented in Africa traditionally to prepare beer. It is a very popular family drink for ceremonial functions. In India also, the fermented beverages by name Hadia is very popular among tribal communities in Jharkhand and so also in Nepal and Bhutan. Finger millet malt mixed with barley malt (50:50) can be brewed to produce commercial lager beer.

Popping: Popping is traditionally adopted to prepare ready to eat snacks from millets. Traditionally, millet grains are popped in hot sand (above 200°C) with continuous agitation. The popped millets are separated by sieving. In case of finger millet, the whole grain is popped which contains seed coat also; while in other small millets during popping, the husk gets flour, develops fine aroma and is extremely popular in south India to make many ready to eat products.

Extrusion cooking: These are modern food processing technologies, widely used in processing technologies, adopted for the preparation of ready to eat snacks, nutritious foods weaning foods, health foods etc. small millets have potential for preparing value added products based on these technology.

Baking: Finger millet flour up to 30-40% can be blended with wheat flour for the preparation of bread, cookies and other baked products. High fibre special bakery products especially made from finger millet is suitable for diabetes.

3.9 Major problems associated with storage of grains:

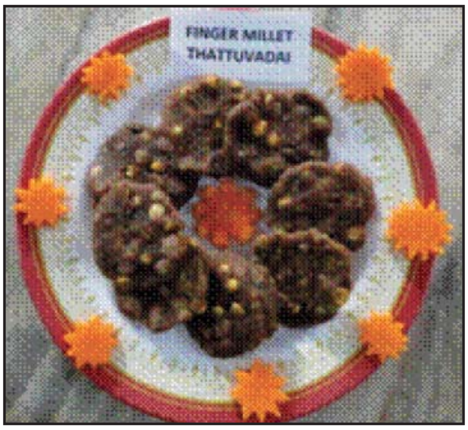
Finger millet store well for quite a long period without infestation by storage pests

3.10 Researchable issues

Research priority decided by AICRIP, ICAR for 12th plan

- Evaluation of core sets for biotic and abiotic stresses as well as quality traits
- Identification of trait specific germplasm for utilization in crop improvement.
- DUS characterization of small millet varieties
- Varieties suitable for mechanical harvesting in all small millets adapted to different agro-climatic situations will be identified
- Development of high yielding varieties with stable resistance suitable to different finger millet growing regions.
- Development of varieties combining resistance to smut with high grain yield.
- Identification of elite germplasm and varieties with superior nutrition traits and bio fortification of elite lines in different small millets.
- Fine tuning of the millet mill with accessories to separate de-husked grains
- Development of Technologies for enhancing shelf life millet rice.
- Training of small-scale entrepreneurs.
- Testing and fine tuning of the available machinery to suit to different small millets.
- Appropriate row proportions for remunerative inter/sequence crops to be identified.
- Moisture, nutrient and crop management options available will be fine tuned for small millets based cropping systems.
- Regular monitoring for disease outbreaks or new diseases is required to be continued.
- IPM against foot rot and sheath blight to be evolved, fine tuned and tested in OFAR trials
- Identification of stable sources of resistance in different small millets
- Evolving IPM module for effective management of shoot fly
- Breeder seed production will be continued as per the requirement
- Transfer of technology (production to consumption) through FLDs

Value added products of Finger millet (Ragi)



Thattuvadia

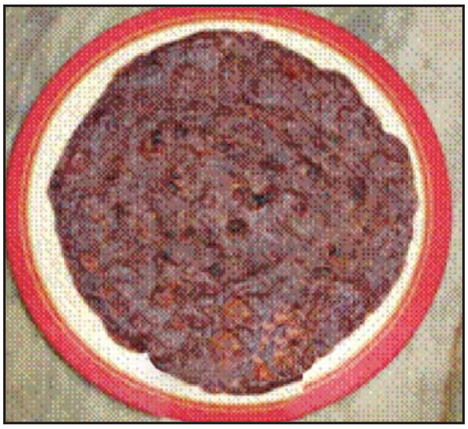

Ragi Wada


Porridge


Pakoda


Uppma


Omapadi


Dosa


Pasta Macaroni


Pasta Ribban


Vermicelli


Pasta Shells


Mudde

Small millets

(Barnyard millet,
Foxtail millet,
Little millet,
Kodo millet,
Proso millet)

4. SMALL MILLETS

Barnyard millet

Foxtail millet

Kodo millet

Proso millet

Little millet

4.1 Introduction

It is a group of crops like barnyard millets, common (*Proso*) millet, foxtail millet, *Kodo* and little millet (*Kutki*) mainly grown in Asian and African countries under varied kind of soils and adverse agro-ecological situations including vide range of temperatures. Some of them are most suited to contingency planning under late receipt of rain, failure of main *Kharif* crops due to long dry spell or even under receding flood situations. **These are extremely important commodities largely cultivated by tribal for their sustenance.** These crops are known with different vernacular names as given in the **Table-28**.

Table-28: Vernacular names of small millets

Name	Small millets				
English	Barnyard millet	Common (*Proso*) millet	Foxtail millet	*Kodo* millet	Little millet
Botanical	*Echinochloa frumentacea*	*Panicum miliaceum*	*Setaria italica*	*Paspalum scrobiculatum*	*Panicum sumatrense*
Vernacular names					
Assamiya	*Koni dhan*	-	-	-	-
Bengla	*Shyama*	*Cheena*	*Kaon*	*Kodo*	-
Gujarati	*Banti*	*Cheno*	*Kang*	*Kodra*	*Gajrao/Kuri*
Hindi	*Sanwa*	*Chena, Bari*	*Kakun, Kangni*	*Kodon*	*Kutki, Savan*
Kannad	*Oodalu*	*Baragu*	*Navane*	*Harika*	*Same/Save*
Malayalam	-	-	*Thena*	*Varaku*	*Sama*
Marathi	*Banti*	*Vari*	*Kang, Rala*	*Kodra*	*Sava*
Oriya	*Khira*	*Bachari*	*Kangam, Kanghzu*	*Kodua*	*Suan*
Punjabi	*Swank*	*Cheena*	*Kangani*	*Kodra*	*Swank*
Telugu	*Oodalu*	*Variga*	*Korra*	*Arika*	*Samalu*
Tamil	*Kutdiravalli*	*Panivaragu*	*Tenai*	*Varagu*	*Samai*

Proximate composition and nutritive value of millets is given in **Table-29**. These crops contains substantially high amount of protein, fibre and minerals in comparison to fine cereals like wheat and rice. The protein content in Millets like *Jowar* (10.4), *Bajra* (11.6), Proso millet (12.5), foxtail millet (12.3) and barnyard millet (11.6) is comparable with wheat (11.8) and much higher than rice (6.8). Though the finger millet contains lesser protein (7.3), but it is rich in mineral matter and calcium in comparison to wheat and rice. All the millets contain more fibre than fine cereals. Particularly, the small millets namely barnyard millet (14.7), *Kodo* millet (9) little millet (8.6) and foxtail millet (8.0) are the richest in fibre in comparison to wheat (1.2) and rice (0.2). **Therefore, millets are now being pronounced as "Miracle grains/*Adbhut Anaj* and nutria-cereals".**

Table-29: Proximate composition of Millets, Coarse cereals and fine cereals

(Per 100 g)

Commodity	Protein (g)	Carbohy-drates	Fat (g)	Crude fibre (g)	Mineral matter (g)	Calcium (mg)	Phosphorus (mg)
Sorghum	10. 4	72. 6	1. 9	1. 6	1. 6	25	222
Pearl millet	11. 6	67. 5	5. 0	1. 2	2. 3	42	296
Finger millet	7. 3	72. 0	1. 3	3. 6	2. 7	344	283
Proso millet	12. 5	70. 4	1. 1	2. 2	1. 9	14	206
Foxtail millet	12. 3	60. 9	4. 3	8. 0	3. 3	31	290
Kodo millet	8. 3	65. 9	1. 4	9. 0	2. 6	27	188
Little millet	8. 7	75. 7	5. 3	8. 6	1. 7	17	220
Barnyard millet	11. 6	74. 3	5. 8	14. 7	4. 7	14	121
Barley	11.5	69.6	1.3	3.9	1.2	26	215
Maize	11.5	66.2	3.6	2.7	1.5	20	348
Wheat	11. 8	71. 2	1. 5	1. 2	1. 5	41	306
Rice	6. 8	78. 2	0. 5	0. 2	0. 6	10	160

Source: National Institute of Nutrition (N IN), Hyderabad

Morphology of small millets

Foxtail millets (Kangni or kakun): It has an erect leafy stem that grows 60-75 cm tall and bends quite a bit at maturity due to heavy weight of earhead. Leaves are narrow (30-45 cm long and 1.25 cm wide) and green in colour. The inflorescence is dense, cylindrical and bristly. The spike is 5-32 cm long and 2-4 cm in diameter often arching towards the tip. Spikelets are 2 flowered protected by the 2 glumes and are generally in clusters of 40 or 50. There are 1-4 bristles at the base of each spike. The common colour of grain is buff.

Kodo *millet*: It is an erect annual with hairy nodes and fully sheated solid internodes. It gains 45-90 cm in height and profusely tillers; up to 18 tillers/plant have been recorded. Leaves are thick and stiff and linear to linear lanceolate. Ligules are membranous and hairy. Both leaves and stems are purple in colour. The inflorescence is a panicle with 2-8 spikes, each having a broad, flat rachis with a series of depressions in which the spikelets are held. Spikelets have a single flower, which opens up in the early morning hours (2.30-3 AM), however, the opening of flowers continues till sunrise. Flower is self-pollinated and seed-setting depends on the weather; drought severely affects it.

Little millet (Kutki or Gunduli)*:* It has an erect and slender stem 45-100 cm height with solid or hollow internodes and distinctly swollen nodes. It tillers profusely. Leaves are linear and slender with leaf sheath hairy at junctions and short-ligule. The inflorescence is large with an open panicle bearing numerous spikelets. Each spikelet has 2 glumes and 2 lemmas of which the second lemma bears hermaphrodite flowers containing 2 lodicules and 2 stamens. The ovary has bifid style and plumose stigmas. Flowers open between 10 AM and 12 noon and close within about 6 min. The fruit, a caryopsis, is globular and enclosed firmly by a lemma and palea. The grains may be creamy white, yellow, red or black.

Proso/Common millet (Cheena): It is an erect annual growing up to 75-100 cm in height; medium to dark purple pigmentation may be noted in plant parts. The stems are slender and leafy up to panicle. The inflorescence is 14-40 cm long oblong panicle having erect hairy branches. The spikelets are solitary or sometimes in pairs, generally 3-4.5 mm long and flattened. Grains are olive brown in colour.

Barnyard millet (Sawan): Its growth habit is same as that of *kodo* millet, i.e. tall erect up to 50-95 cm in height, but the stem as well as leaves are green in colour. Its leaves are flat, glabrous or slightly hairy without ligule. The inflorescence is usually narrow pyramidal thickened with densely crowded unawned spikelets in 3-5 rows. The second lemma bears hermaphrodite flowers with 3 stamens and 2 styles with plumose stigmas. Flower starts at about 5 am and continues upto 10 am. The grain is caryopsis and white or yellow in colour.

Brief details of Small millet crops

Crop	Particulars	
BARNYARD MILLET: *Echinochloa colona* (L.) *Link*.	Origin	India
	Existential	Minuscule food, cattle fodder, cattle & poultry feed.
	Ecology	Adapted to temperate climatic & grows well in tropics also on soils with fragile ecology.
	Temperature	Tolerant to very wide temperature range.
	Altitude	Up to 2700 metres.
	Rainfall	200 – 400 mm.
	Distribution	
	Global	Tanzania & Malawi republic of Africa. In Asia, India, Nepal, Japan, Korea and China.
	India	Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra, Tamilnadu & Uttarakhand.
COMMON (PROSO) MILLET: *Panicum milliaceum* L.	Origin	Central & Eastern Asia
	Existential	Minuscule food with medicinal properties being rich in Choline with traces of Manganese, Copper & Zinc and minerals like calcium, phosphours & iron, hog feed, cattle fodder, bedding and starch for sizing textiles.
	Soils	Marginal shallow lands with no humus.
	Temperature	Tolerant to very wide temperature range.
	Altitude	Up to 2700 metres.
	Rainfall	200-400 mm.

Crop	Particulars	
	Pollination	Partly self & Partly cross-pollinated.
	Distribution	
	Global	Neolithic Europe, Volga region of Russia, Kazhakhistan, Bangladesh, Srilanka, Nepal & China, North & West America, Kenya, Zimbabwe, Ethiopia & India.
	India	Andhra Pradesh, Bihar, Gujarat, Karnataka, Maharashtra, Rajasthan and Tamilnadu.
FOXTAIL MILLET: *Setaria italica*. Beauv.	Origin	Eastern Asia.
	Existential	Minuscule food rich in minerals, popped culinary & cattle fodder.
	Ecology	Adapted to too hot & dry climate. Grown in temperate regions to tropic.
	Soils	Marginal shallow lands with no humus. Grown mostly as companion crop with cotton/pulses/ oilseeds.
	Temperature	Tolerant to very wide temperature range.
	Rainfall	200-400 mm.
	Distribution	
	Global	Eurasia, Ethiopia, Zimbabwe, Japan, China, Nepal & India.
	India	Andhra Pradesh, Gujarat, Maharashtra, Rajasthan & Tamilnadu.
KODO MILLET: *Paspalum scrobiculatum* L.	Origin	India
	Existential	Minuscule food, cattle & cattle fodder.
	Ecology	Kodo millet can grow where no other cereal grows. Adapted to very hot & dry climate.
	Soils	Marginal soil with no humus, hilly slopes/edges.
	Distribution:	
	Global	Uganda
	India	Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Chhattisgarh, Madhya Pradesh and Tamilnadu.
LITTLE MILLET: *Panicum sumatrense Roth Ex. Roem & Schult*	Origin	Arid western North America.
	Existential	Minuscule food, cattle fodder.
	Ecology	A very hot & dry season crops grown on marginal lands & hilly slopes.
	Temperature	Tolerant to very wide temperature range.
	Rainfall	200-400 mm.
	Altitude	Up to 2100 metres.
	Distribution:	
	Global	South East Asia, China & India.
	India	Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Orissa and Tamilnadu.

4.2 Comparative analysis

Madhya Pradesh occupied highest area of small millets (32.4%) followed by Chhattisgarh (19.5%), Uttarakhand (8%), Maharashtra (7.8%), Gujarat (5.3%), Tamilnadu (3.9%), Karnataka, Andhra Pradesh, Jharkhand, Arunachal Pradesh, Odisha, Nagaland, Rajasthan, Uttra Pradesh. Uttrakhand has highest productivity of 1166 Kg/ha followed by Tamil Nadu (1067 Kg/ha) and Gujarat (1020 Kg/ha). State-wise average area, production and yield estimates of small millets are given in **Table-30**.

Table-30: State-wise Normal Area, Production and Yield of Small millets (Average of 2007-08 to 2011-12)

States	Area ('000'ha)	Production ('000' tonnes)	Yield (Kg/ha)
Andhra Pradesh	30.8 (3.36)	19.4 (4.22)	630
Arunachal Pradesh	21.9 (2.39)	19.6 (4.26)	897
Assam	6.2 (0.68)	3.3 (0.72)	531
Bihar	5.5 (0.60)	4.2 (0.91)	758
Chhattisgarh	178.5 (19.47)	38.8 (8.44)	218
Gujarat	48.8 (5.32)	49.8 (10.83)	1020
Himachal Pradesh	6.3 (0.69)	4.0 (0.87)	636
Jammu & Kashmir	8.9 (0.97)	4.5 (0.98)	510
Jharkhand	25.0 (2.73)	12.0 (2.61)	480
Karnataka	32.0 (3.49)	15.3 (3.33)	477
Madhya Pradesh	297.1 (32.40)	85.6 (18.62)	288
Maharashtra	71.4 (7.79)	34.5 (7.50)	483
Nagaland	16.3 (1.78)	12.0 (2.61)	737
Orissa	18.1 (1.97)	8.9 (1.94)	489
Rajasthan	16.2 (1.77)	5.7 (1.24)	354
Tamil Nadu	36.1 (3.94)	38.5 (8.37)	1067
Uttar Pradesh	13.2 (1.44)	9.1 (1.98)	695
Uttarakhand	73.4 (8.00)	85.6 (18.62)	1166
Others	11.4 (1.24)	9.0 (1.96)	791
All India	**917.0**	**459.8**	**501**

4.3 Varietal development

In comparison to sorghum, pearl millet and finger millet limited varieties of small millet have been developed. During last 15 years only 34 varieties of 6 crops namely kodo millet (9), little millet (6), foxtail millet (5), barnyard millet (6) and proso millet (8) have been released for different states. Out of these 34 new varieties only 11 have become popular in the states of **Gujarat, Karnataka, Tamilnadu and Uttrakhand**, whereas, in Chhattisgarh and Madhya Pradesh none of the new variety could reached to the farmers. The State wise position is given below in **Table-31**.

Table-31: Adoption of improved varieties

Crop	State	Varieties released/recommended during last 15 years.	Varieties popular in the State
Kodo (9)	A.P.	JK-48.	None
	Chhattisgarh	JK-13 and JK-48.	JK-41, JK-76 and GPUK-3
	Gujarat	RK 65-18, GK-2, JK-48 and JK-65	GK-1 and GK-2.
	Karnataka	JK-13, JK-48 and RBK-155.	GPUK-3, RBK-155 and DPS-48.
	M.P.	JK-13, JK-48, JK-65, JK-106, JK-439, RK 65-18 and RBK-155.	JK-21, JK-48, RBK-155, K-106 & JK-76.
	Tamilnadu	Vamban and JK-13.	K-1, CO-2, CO-3, APK-1 and Vamban.
	U.P.	KK-2, JK-13, JK-65 & RK 65-18	-
Little millet (6)	A.P.	Tarini (OLM 203)	-
	Bihar	Tarini & Kolab (OLM-36).	-
	Chhattisgarh	Kolab, Sabara, OLM-20, OLM-208 & OLM-217.	JK-1, VG-1 and TNAU-63
	Gujarat	OLM-208, OLM-217, Kolab and TNAU-63.	-
	Karnataka	Tarini, Kolab and TNAU-63.	TNAU-63, OLM-20, OLM-3 & OLM-203.
	MP	Kolab, Sabara and Jawahar Kutki-36.	JK-8, JK-36, CO.2, PRC-3.
	Orissa	OLM-217, OLM-208, OLM-20, Tarini, Kolab and Sabara.	-
	Tamilnadu	TNAU-63, CO-3, Paiyur-2 and OLM-203.	K-1, CO-2, CO-3, CO-4, Paiyur-1 and Paiyur-2.
Foxtail millet (5)	A.P.	Pant Setaria-4, TNAU-186 and Srilaxmi.	Krishnadevaraya
	Chhattisgarh	Pant setaria-4.	-
	Karnataka	Pant setaria-4, HMT-100-1 and TNAU-186	SIA-326, PS-4 and TNAU-186.
	MP	Pant Setaria-4.	-
	Maharashtra	Pant Setaria-4.	-
	Orissa	Pant Setaria-4.	-
	Rajasthan	SR-16, SR-1 and SR-51.	
	Tamilnadu	TNAU-43, CO (Te)-7, PS-4, TNAU-196 & TNAU-186.	K-2, K-3, CO-4, CO-5, CO-6 & CO (Te)-7.
	UP	Pant setaria-4 & PRK-1	-
	West Bengal	Pant setaria-4	-

Table-31 contd…

Crop	State	Varieties released/recommended during last 15 years.	Varieties popular in the State
Barnyard millet (6)	Bihar	VL-Madira-181 and VL-207	-
	Gujarat	VL-Madira-172	-
	Jharkhand	VL-Madira-181 and VL-207	-
	Karnataka	VL-Madira-172, VL-Madira-181, VL-207 and RAU-11	VLM-181, VLM-172 and VLM- 29.
	MP	VL-Madira-181 and VL-207	-
	Rajasthan	VL-207.	-
	Tamilnadu	VL-Madira-181	CO-1, K-1 and K-2.
	UP	VL-207 and VL-Madira-172	-
	Uttrakhand	VL-Madira-172, VL-207 and PRJ-1	VLM-172, VLM-29, VL-207 & PRJ-1.
Proso millet (8)	AP	TNAU-151 and TNAU-164.	-
	Bihar	TNAU-151 and TNAU-164.	-
	Karnataka	GPUP-8, GPUP-21, TNAU-145, TNAU-151 and TNAU-164.	GPUP-8 and GPUP-21.
	Maharashtra	TNAU-164.	-
	Rajasthan	Pratap chena-1.	-
	Tamilnadu	GPUP-21, CO (Pv)-5, TNAU-145, TNAU-151 and TNAU-164.	K-1, K-2, CO-2, CO-3, CO-4 and CO (Pv)-5.
	Uttarakhand	PRC-1, TNAU-164 and TNAU-151	-

Yield potential and gap: Though only a limited number of varieties of small millet have been developed. These varieties have remarkably shown higher yield than the State average yield of the concerned crops achieved so far. The crop and variety wise yield potential and State average yield of small millets given below in **Table-32** reveals a larger yield gap which could be exploited for making these nutritious crops more profitable.

Table-32: Crop/variety wise yield potential of small millets

Crop	Variety	Yield potential (Kg/ha)	Maximum State average yield (Kg/ha)
Kodo	JK-48	2648	1259 (Tamilnadu)
Little millet	Tarini	1223	761 (Karnataka)
Foxtail millet	HMT-100-1	2000-2500	691 (Andhra Pradesh)
Barnyard millet	PRJ-1	2500	1138 (Uttrakhand)
Proso millet	GPUP-8	2500	387 (Uttar Pradesh)

FLDs of small millets (kodo millet, foxtail millet, little millet, barnyard millet and proso millet) have been organized by the All India Coordinated Small Millets Improved Project, Bengaluru over an area of 980.02 ha during 2007-08 to 2012-13 through its centres located in Andhra Pradesh, Chhattisgarh, Gujarat, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Tamil Nadu, Uttar Pradesh and Uttarakhand on improved package of practices including value addition. The state wise progress of FLDs of small millets is given in **Table-33**.

Table-33: Crop-wise details of FLDs

Crop	States	Area under FLDs (ha)					
		2007-08	2009-10	2010-11	2011-12	2012-13	TOTAL
Kodo millet	Chhattisgarh	10.0	-	10.0	6.8	9.0	35.8
	Karnataka	-	-	-	8.8	10.0	18.8
	M.P.	16.7	16.7	33.8	68.6	21.2	157.0
	Tamilnadu	25.0	4.0	10.0	20.0	10.0	69.0
	Uttar Pradesh	-	3.0	-	-	-	3.0
	TOTAL	**51.7**	**23.2**	**53.8**	**104.2**	**50.2**	**283.1**
Foxtail millet	A.P.	30.0	-	38.0	30.5	25.0	123.5
	Karnataka	27.5	-	22.4	61.8	67.8	179.5
	TOTAL	**57.5**	**0**	**60.6**	**92.3**	**92.8**	**303.2**
Little millet	Andhra Pradesh	-	-	-	-	11.0	11.0
	Chhattisgarh	10.0	-	-	-	-	10.0
	Gujarat	-	-	-	-	10.0	10.0
	Jharkhand	-	-	-	12.0	-	12.0
	Karnataka	20.0	-	24.6	41.2	24.5	110.3
	M.P.	4.1	7.3	12.8	22.8	19.2	66.2
	Maharashtra	-	-	-	2.0	-	2.0
	Orissa	4.0	-	-	5.2	10.0	19.2
	Tamilandu	15.0	7.0	10.0	20.0	10.0	62.0
	TOTAL	**53.1**	**14.3**	**47.4**	**103.2**	**84.7**	**302.7**
Barnyard millet	Tamil Nadu	-	-	-	10.0	10.0	20.0
	Uttrakhand	5.9	2.7	6.7	7.7	18.9	41.9
	TOTAL	**5.9**	**2.7**	**6.7**	**17.7**	**28.9**	**61.9**
Proso millet	Karnataka	-	-	-	-	19.3	19.3
	Tamil Nadu	-	-	-	-	10.0	10.0
	TOTAL	**-**	**-**	**-**	**-**	**29.3**	29.3
	GRAND TOTAL	**168.2**	**40.2**	**168.5**	**317.4**	**285.9**	**980.2**

The yield performance of FLD is given in **Table-34.**

Table-34: The yield performance of FLDs of small millets

Sl. No.	State	Factor	2007-08	2009-10	2010-11	2011-12	2012-13	Mean
		Year-wise yield (Kg/ha)						
(1) Kodo millet								
1	Chhattisgarh	FLD	1200	-	1444	1016	1450	1278
		Control	1300	-	600	363	473	684
		% Gap over control plot						87
2	Karnataka	FLD	-	-	-	-	612	612
		Control	-	-	-	-	359	359
		% Gap over control plot						70
3	Madhya Pradesh (sole crop)	FLD	-	946	1304	1579	1277	1277
		Control	-	419	659	827	638	636
		% Gap over control plot						101
4	Madhya Pradesh (Inter crop)	FLD	1414	365	-	2460	1604	1461
		Control	674	226	-	1423	1159	871
		% Gap over control plot						68
5	Tamilnadu	FLD	3360	3661	3593	1752	2634	3000
		Control	2237	2737	2730	1377	1969	2210
		% Gap over control plot						36
(2) Foxtail millet								
1	Andhra Pradesh	FLD	4830	-	1739	2628	1563	2690
		Control	3298	-	1297	1861	1218	1919
		% Gap over control plot						40
2	Karnataka	FLD	2375	-	1775	2016	1475	1910
		Control	1733	-	963	1190	835	1180
		% Gap over control plot						62
(3) Little millet								
1	Karnataka	FLD	1080	-	1590	1405	1465	1385
		Control	964	-	972	945	845	932
		% Gap over control plot						49
2	Madhya Pradesh (sole crop)	FLD	-	677	1060	492	1234	866
		Control	-	340	575	203	670	447
		% Gap over control plot						94
3	Madhya Pradesh (Inter crop)	FLD	1259	342	739	1800	1391	1106
		Control	466	195	436	681	795	515
		% Gap over control plot						115

Sl. No.	State	Factor	Year-wise yield (Kg/ha)					
			2007-08	2009-10	2010-11	2011-12	2012-13	Mean
4	Maharashtra	FLD	-	-	-	1363	-	1363
		Control	-	-	-	700	-	700
		% Gap over control plot						95
5	Orissa	FLD	1150	-	1250	1150	1310	1215
		Control	680	-	650	570	640	635
		% Gap over control plot						**91**
6	Tamilnadu	FLD	1118	1908	1647	1441	1211	1465
		Control	782	1378	990	852	725	945
		% Gap over control plot						**55**
(4) Barnyard millet								
1	Tamil Nadu	FLD	-	-	-	1752	1434	1593
		Control	-	-	-	1377	1129	1253
		% Gap over control plot						**27**
2	Uttarakhand	FLD	1592	1473	1615	1497	1517	1539
		Control	956	938	986	1050	1135	1013
		% Gap over control plot						**52**
(5) Proso millet								
1	Karnataka	FLD	-	-	-	-	1840	1840
		Control	-	-	-	-	1153	1153
		% Gap over control plot						**60**
2	Tamil Nadu	FLD	-	-	-	-	1460	1460
		Control	-	-	-	-	1152	1152
		% Gap over control plot						**27**

The yield performace of FLD of small millets given in **Table-7** reveals gap over the control plot/ farmer practice yield of all small millets. The crop-wise salient features are summarized as under:-

Kodo millet: Largest yield gap has been recorded in Madhya Pradesh (101%) followed by Chhattisgarh (87%), Karnataka (70%) with least yield gap in Tamilnadu (36%) over control plot.

Foxtail millet: Yield gap of 62% and 40% has been recorded in Karnataka and Andhra Pradesh over control plot.

Little millet: The largest yield gap has been recorded in Madhya Pradesh (115%) followed by Maharashtra (95%), Odisha (91%), Tamilnadu (55%), and Karnataka (49%).

Barnyard millet: Yield gap of 52% and 27% has been recorded in Uttarakhand and Tamil Nadu over control plot.

Proso (Common) millet: Yield gap of 60% and 27% has been recorded in Karnataka and Tamil Nadu over control plot.

4.4 Climatic requirement

Small millets are grown on a wide variety of soils ranging from loamy sand alluvial soils to clayey black cotton soils (Vertisols). *Kodo* and some other small millets can be grown in gravelly and stony soils also such as in the hills regions. These are grown on soils belonging to soil orders Alfisols, Entisols, Inceptisols, Aridisols, Mollisols, Vertisols, Ultisols, Oxisols.

Most small millets other than *S. italica* are grown in warm regions and can tolerate temperature of 35-40^{0}C, however, for growth the ideal temperature is 26-29^{0}C. For *kodo* millet, which has a heavy water requirement due to low transpiration co-efficient a minimum rainfall of 25-35 cm is required, but it grows well in moderate rainfall of 50-60 cm. *Setaria italica* can be grown in tropics as well as temperate regions both under low and moderate rainfall. This can be grown as a summer, rainy season and post-monsoon season crop.

Climate resilience of the crop

Small millets have good resilience to soil, moisture & weather parameter, therefore, has high capacity in terms of drought tolerance and can be stored without spoilage for many years and hence are called '**famine reserves'**

4.5 Genetic potentiality advancement

Since the inception of the AICSMIP, ICAR, more than 100 high yielding, disease/pest resistant varieties in different small millets have been released suiting to different agro climatic conditions and seasons for the benefit of farming community. Barnyard millet variety PRJ 1 has been well received by the farmers and made significant impact on productivity.

4.6 Recommended package of practices

Recommended package of practices by ICAR is given below:-

Sl. No.	Operation	Small millets				
		Kodo	**Kutki / LM**	**Barnyard**	**Foxtail**	**Proso millet**
		Time of Sowing				
1.	Kharif	-	-	April-May - Uttarakhand	July-Aug - Kar	-
		Mid June - End of July	June – Odisha, TN	-	July– TN, AP	July
		-	May-June & Sep-Oct Karnataka	-	2-3 week July Maharashtra	-
	Rabi	-	June-July – MP, Bihar	Sep-Oct - TN	Aug-Sep - TN	Sep-Oct: TN, AP
	Summer	-	-	-	-	March-April - Bihar
2.	**Method of sowing**					
	Manual (%)	100	100	100	100	100

Sl. No.	Operation	Small millets				
		Kodo	Kutki / LM	Barnyard	Foxtail	Proso millet
3.	**Seed**					
	Seed Rate	10 kg/ha	8 kg/ha	8 kg/ha	8 kg/ha	10 kg/ha
	Row to row and Plant to plant Distance	22.5-30cmx10 cm	22.5cmx 10cm	25cmx10cm	25-30cm/ 8-10cm	25cmx 10cm
	Ideal plant population/ha	4-5 lakh per ha	4-5 lakh per ha	4-5 lakh per ha	4-5 lakh per ha	4-5 lakh per ha
Seed treatment						
	Fungicides Names & Dose)	Chlorothalonil or Carbendazim @ 2gkg^{-1}	Carboxin or Carbendazim @2gkg^{-1}	Carbendazim @2gkg^{-1}	Ridomil mz @2gkg^{-1} Carbendazim @2gkg^{-1}	
	Bio-fertilizer (Name & Dose)	*Azospirillum brasilense or Aspergillus awamouri @* 25 g/kg seed	*As in kodo*	*Azospirillum brasilense and Aspergillus awamouri* @25g/kg seed	As in barnyard millet	As in barnyard millet
4.	**Fertilizer doses**					
	Kharif (Rainfed)					
	Urea	26	26	26	52	26
	DAP	44	44	44	33	44
	Manures	5-7.5 t/ha	5-7.5 t/ha	5-7.5 t/ha	5-7.5 t/ha	5-7.5 t/ha
5.	**Weeds Control**					
	Name of major weeds	**Monocots** – *Digitaria marginata, Cynodon dactylon, Cyp. rotundus, Setaria glauca, Crommelina benghalensis* etc. **Dicots** – *Euphorbia hirta, Leucas aspera, Acanthospermum hispidum Phylanthus niruri, Amaranthus viridis* etc.				
	Weedicides (name, dose and time of application)	Isoproturon (0.5 ai/ha)- Pre-emergent (rainfed / drilled 2,4D(0.75 kg ai/ha) – Post emergent (15-20 DAS)				
6.		**Disease/Pest Management**				
	Name of major Disease/pest	shootfly	shootfly	shootfly	shootfly	shootfly
	Major Diseases	Head smut	Grain smut	Grain smut	Blast Downy mildew Rust	No major disease
	Control measures for pest	1. Early sowing in the month of May will escape 2. In late sown crop increase the seed rate one and half times 3. Seed treatment with chloropyriphos @ 2 ml / lit water for 1 kg seed or imidachloprid @ 0.7 ml / lit water				

Sl. No.	Operation	Small millets				
		Kodo	Kutki / LM	Barnyard	Foxtail	Proso millet
	Name of fungicides				Mancozeb @ 2g/lit	
	IPM				1. Rogue out downy mildew affected plants 2. Give sprays only if diseases appear at early stage of crop growth	
6.	**Harvesting & Threshing**					
	Kharif	November	October-November	October-November	October-November	October-November
	Rabi/Summer	-	-	-	April	June
	Harvesting					
	Manual (%)	100	100	100	100	100
	Threshing					
	Manual (%)	100	100	100	100	100

Note:* Based on soil test DAS: Days after Sowing

4.7 Cropping system

Table-35: Inter cropping with small millets.

Crop	State	Inter cropping
Little millet	Bihar	Little millet : pigeon pea; little millet : sesame.
	Karnataka	Little millet : green gram (4:2)
	Madhya Pradesh	Little millet : soybean; little millet : sesame.
	Orissa	Little millet : black gram; little millet : sesame.
Kodo	Madhya Pradesh	Kodo millet : short duration pigeon pea (2:1/8:2); Kodo millet : oil seeds.
Barnyard	Uttar Pradesh	Barnyard millet : rice bean (4:1)
Foxtail millet	Andhra Pradesh	Foxtail millet : pigeon pea
	Karnataka	Foxtail millet : cotton; Foxtail millet : field bean (4:2); foxtail millet : pigeon pea
Proso millet	Bihar	Proso millet : green gram

4.8 Potential states and districts

Prior to green revolution these crops were grown over an area of > 44 lakh ha (mean of 1961-66) in almost all the part of the country, which has been declined heavily to less than 9.17 Lakh ha (2011-12) spread over in 91 districts of 9 States. The crop wise potential States and districts having > 2,000 ha of small millets are given below in **Table-36**.

Table-36: List of potential districts of small millets

Sl. No.	Crop	State	Potential districts
1	Barnyard millet	Chhattisgarh	Dantiwada, Sarguja and Korea.
		Madhya Pradesh	Chhindwara, Seoni, Sidhi, Jhabua, and Betul.
		Maharashtra	Nasik.
		Tamilnadu	Madurai.
		Uttar Pradesh	Sonbhadra
		Uttrakhand	Chamoli, Pauri Garhwal, Tehri Garhwal, Uttar Kashi and Almora.
2	Foxtail millet	Andhra Pradesh	Kurnool and Mahboobnagar.
		Gujarat	Valsad, Dang, Patan and Banaskantha.
		Karnataka	Belgaum, Bellary, Chitradurga and Koppal
		Madhya Pradesh	Seoni.
		Maharashtra	Nasik.
3	Kodo	Chhattisgarh	Raipur, Durg, Rajnanadgaon, Bilaspur, Sarguja, Bastar, Kanker and Dantewada.
		Maharashtra	Nasik.
		Madhya Pradesh	Jabalpur, Balaghat, Chhindwara, Seoni, Mandla, Panna, Chhatarpur, Rewa, Sidhi, Satna, Shahdol and Betul.
		Tamilnadu	Cuddalore and Perambalur.
4	Little millet	Andhra Pradesh	Vishakhapatanam and Chittoor.
		Chhattisgarh	Raipur, Rajnanadgaon, Durg, Bilaspur, Raigarh.
		Jharkhand	Ranchi, Palamu, Garhwa and Gumla.
		Karnataka	Belgaum, Chitradurga, Dharwad, Haveri and Tumkur
		Madhya Pradesh	Jabalpur, Balaghat, Chhindwara, Seoni, Mandla, Sidhi, Khargone and Betul.
		Maharashtra	Nasik.
		Orissa	Bolangir, Koraput, Rayagada, Mayurbhanj and Sundergarh.
		Tamilnadu	Vellore, Thiruvannamalai, Dharmapuri and Krishnagiri.
5	Proso millet	Maharashtra	Thane, Raigad, Nasik, Dhule and Pune.

4.9 Crop products

Small millets traditionally used as roti, khichdi, pulao, dokla, etc. Value added food for devotees (barnyard millet), feed, value added food products for diabetics are the other use of small millets. Some products of small millets are given below:-

Flakes: Small millets grain can be given secondary processing to prepare flakes or pre-gelatinized food material. The flakes may be used to prepare snacks by subjecting to blistering by high temperature and short time treatment using salt, air or oil as the heat transfer media. The blistered material will have flowery attractive look and crisp taste and are amendable for coating with spice or malt extract and such other desirable additives. The meal from the milled grains has potential for preparation of fabricated foods, noodle or simply to use for the preparation of many traditional food items.

Extrusion cooking: The milled material contains good amount of starch and exhibit good extrusion cooking characteristics. The millet grits equilibrated to about 18% moisture on extrusion cooking form well expanded ready-to-eat food products with porous and crunchy structure. The extruded material can be prepared in different shapes and sizes such as flakes, small balls or cheese rolls or can be pulverized into grits for different end uses.

Roller drying: The flour from the millets could be roller dried to prepare a ready-to-eat food, most suitable as a thickener in soup or porridge. The roller dried millet may also find usage as a component to edible films. The nutrient composition and some of the functional properties of the millets processed adapting contemporary food processing technology such as extrusion cooking, roller drying, flaking and popping indicate their potential for preparation of value added products.

4.10 Researchable issues

Research priorities decided by AICRIP, ICAR for 12th plan

- Evaluation of core sets for biotic and abiotic stresses as well as quality traits
- Identification of trait specific germplasm for utilization in crop improvement.
- DUS characterization of small millet varieties
- Varieties suitable for mechanical harvesting in all small millets adapted to different agro-climatic situations will be identified
- Development of high yielding varieties with stable resistance suitable to different finger millet growing regions.
- Development of varieties combining resistance to smut with high grain yield.
- Identification of elite germplasm and varieties with superior nutrition traits and bio fortification of elite lines in different small millets.
- Fine tuning of the millet mill with accessories to separate de-husked grains
- Development of Technologies for enhancing shelf life millet rice.
- Training of small-scale entrepreneurs.
- Testing and fine tuning of the available machinery to suit to different small millets.
- Appropriate row proportions for remunerative inter/sequence crops to be identified.
- Moisture, nutrient and crop management options available will be fine tuned for small millets based cropping systems.
- Regular monitoring for disease outbreaks or new diseases is required to be continued.
- IPM against foot rot and sheath blight to be evolved, fine tuned and tested in OFAR trials
- Identification of stable sources of resistance in different small millets
- Evolving IPM module for effective management of shoot fly
- Breeder seed production will be continued as per the requirement
- Transfer of technology (production to consumption) through FLDs

Value added products of Small millets

Barnyard millet

Ribban Pakoda

Murukku

Vadagam

Paniyaram

Idli

Roti

Wada

Halwa

Value added products of Small millets

Foxtailmillet

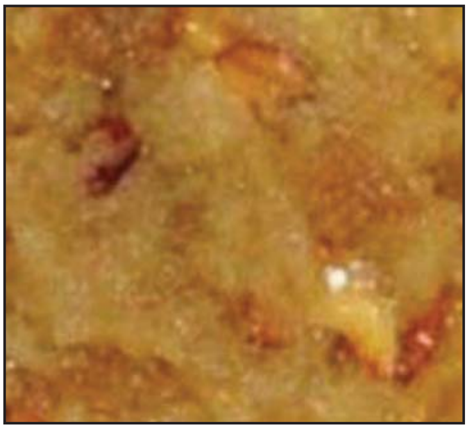

Idli

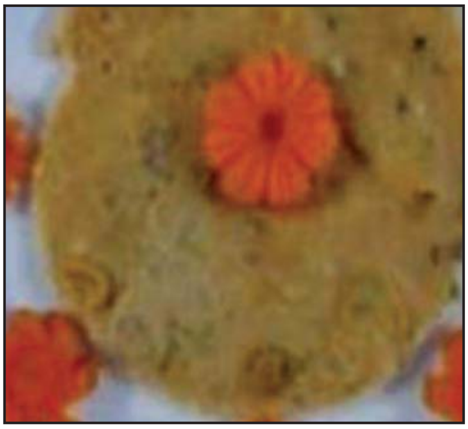

Murukku


Pakoda


Paniyaram

Little millet


Halwa


Adai


Idiyappam


Idli

Value added products of Small millets

Kodomillet

Halwa

Kheer

Roti

Restri

Ribban Pakoda

Murukku

Idli

Paniyaram

Value added products of Small millets

Proso millet

Adhirasam

Dosa

Payasam

Vada

Maize

5. MAIZE (*Zea mays*)

5.1. Introduction

The primary centre of origin of maize is considered by most authorities to be the Central America and Mexico, because of maximum maize genetic diversity existed in the region. The discovery of fossil maize pollen with other archaeological evidence in Mexico indicates Mexico to be the native home of maize. The studies indicate that maize was a significant crop in Mexico 5,000 years ago and perhaps earlier. American Indians grew and selectively improved maize from 3400 B.C. to 1500 A.D.

The maize plant was unknown in the old world before 1492, by the time Columbus arrived in America. In Europe maize was first introduced in Spain sometimes after Columbus returned from his second voyage. The plant was first grown in Europe as a garden curiosity. Later on, it spread from Spain to southern France and Italy. Its introduction into India probably occurred about the beginning of the seventeenth century, during the early days of the East India Company.

Maize is one of the most important cereal crops in the world agricultural economy both as food for man and feed for animals. It is a miracle crop. It has very high yield potential, there is no cereal on the earth which has so immense potentiality and that is why it is called *'queen of cereals'.* Besides, maize has many types like normal yellow, white grain, sweet corn, baby corn, pop corn, waxy corn, high amylase corn, high oil corn, quality protein maize, *etc*.

In India Maize is third important crop after rice and wheat that provides food, feed and fodder and serves as source of basic raw material for the number of industrial products, *viz*. starch, oil, protein, alcoholic beverages, food, sweeteners, cosmetics, bio-fuel, *etc*.

Maize is primarily used for feed (64%) followed by human food (16%), industrial starch and beverage (19%) and seed (1%). Thus, Maize has attained an important position as industrial crop because 83% of its produce is used in starch and feed industries (Source: DMR).

Maize consists of three main parts – the full or bran coat with high fibre content, germ rich in oil and starchy endosperm. The normal maize grain under Indian conditions on an average, contains 14.9% moisture, 9 to 11% protein, 3.6% fat, 2.7% fibre, 66.2% other carbohydrates and 1.5% minerals (NIN, 2002). Maize kernel protein is made up of five different fractions. The percentage of different fractions to total nitrogen in maize kernel is albumin 7%, globulin 5%, non-protein nitrogen 6%, prolamine 52% and glutelin 25% and the left over 5% is residual nitrogen. Protein being the primary structural and functional component of every living cell is one of the most important ingredients that determine the quality of food and feed (Source: "Quality Protein Maize for Food & Nutritional Security in India" published by DMR, ICAR).

Maize is one of the world's leading crops cultivated over an area of about 163 million ha with a production of about 835 million tons of grain (FAO Year book 2013). The United States produces 38.34% of the world's harvest. Other top producing countries include China, Brazil, Mexico, Argentina, India, Indonesia, France, Ukraine, and South Africa.

The maize is cultivated throughout the year during *kharif* (85%), *rabi*/ summer (15%) season. During 2012-13 maize production is estimated at 22.26 million tonnes ever all time record production in the country as compared to last year's production of 21.76 million tons. Maize is grown in almost all the states of India. Andhra Pradesh, Karnataka, Bihar, Maharashtra, Rajasthan, Madhya Pradesh and Uttar Pradesh are the major maize producing states. Though the maximum acreage is in Karnataka and production of maize is in Andhra Pradesh due to second highest average yield per ha (4505 kg) while maximum productivity is in Tamil Nadu (4691 kg). The productivity of maize during last 12 years (2001-2012) was enhanced @ 61 kg/ha per year in comparison to productivity enhancement of 26 kg/ha per year between 1950-2000 due to better technology, improved varieties/hybrids and good quality of seeds.

There are several value added products of maize particularly Quality Protein Maize (QPM) and food dishes including *chapaties* l*adoo, halva, kheer, sev, mathi etc.* are prepared out of maize flour and grain. It is also a good feed for poultry, piggery and other animals. It ranks below wheat and sorghum but considerably above rice in nutrition. The QPM has got special distinction among the cereals due to presence of high amount of two essential amino acids *viz*., lysine and tryptophan and low content of non-desirable amino acid (leucine). Green cobs are roasted and eaten by people with great interest. The special variety called the 'Pop corn' the grains of which are characterized by a hard corneous interior structure, are converted into the 'popped' from which is the favorite food for children in the cities. Baby corn is a young finger like unfertilized cob of maize preferably harvested within 1-3 days of silk emergence depending upon season used for salads, *chutney*, vegetables, pickles, *kheer*, Chinese preparation, *etc*. Besides, maize is also used as fodder, fuel and ethanol purposes.

Maize belongs to C_4 photo system (plants that use C_4 photosynthesis to fix atmospheric carbon dioxide). C_4 photosynthesis is so called because the initial product of photosynthesis is a four carbon compound (oxaloacetate). C_4 photosynthesis essentially eliminates the oxygenase activity of Rubisco via anatomical, biochemical and ultra structural modifications of leaves (Brown *et al*., 2005).

Morphology of maize

Maize (*Zea mays L*) belongs to *poaceae* family. It is a medium to tall annual plant which usually grows to a height of one meter to 3 meters or more in some cases. The botanical description of main parts of maize plant is given below:-

Root System

The root system of maize is fibrous and deep. It is usually well developed. It consists of (a) seminal roots, (b) crown of coronal roots, and (c) brace or aerial roots.

(a) *Seminal or Temporary roots*: Consists of radicle and a number of lateral roots (usually 3-5) which arise at the base of the first node of the stem under soil surface just above the scutellar node.

(b) *Crown of Coronal roots*: They arise from the basal portion of the stem. The first four of five crown roots appear at the base of the second internode as soon as the tip of the coleoptile reaches the soil surface. These are actually functional roots. Following the seedling stage, they constitute the principal part of the root system.

(c) *Brace, Prop of Aerial Roots*: They arise from second, third and sometime fourth nodes above the soil surface. All may or may not enter the soil. Their primary function is to give anchorage to the plants.

Stem: The stem is made up of approximately 12-18 alternating nodes and internodes, and is completely filled with the pith. The number of internodes may vary but on an average there are 14 internodes. A leaf is attached to each node, and often a bud of branch arises at a node. Internodes are somewhat flattened or grooved on the side next to the leaf sheath.

Leaves: The leaves of maize develop alternately on opposite sides of the stem. Each leaf consists of a thin, flat and expanded blade with a definite midrib and smaller veins and a thicker, more rigid sheath. Each sheath surrounds the inter node above the node to which it is attached. The number of leaves varies from 12 to 20. Stomata are present on both the surface of leaf.

Inflorescence: Maize is normally a monoecious plant having two types of inflorescence, the female inflorescence which develops into an ear (cob) and the male inflorescence, which contains the male flowers. The flowers are borne on two different parts of the plant. The male flowers are borne in a cluster (tassel) on the top of end of the stem as a terminal panicle, while the female flowers are borne inside the young cobs which spring from one of the nodes on the stem usually located about midway on the stalk. The branches of the tassel are spirally arranged around the axis. The spikelet is usually arranged in pairs, one sessile and the other pedicellate. Each spikelet is enclosed by two glumes. There are two florets per spikelet. Each floret contains three stamens, two lodicules and a rudimentary pistil.

The female spikelets have single flower, sessile and densely packed in several vertical series on the thick and cylindrical rachis. The style is a very long silky filament the cluster of which is known as silk and the ovary is obliquely ovoid.

At anthesis just prior to shedding of pollen, the lodicules swell to several times their former size and push the palea and lemma apart, making it possible for the anthers to be extruded by the elongating filaments. Anthers then break open near the tip, forming pores through which the pollens are shed in huge number in the wind. In each plant, tassel usually sheds some of its pollen before the skills of its ears emerge from the husks. Pollen shed continues for about a week. When the pollen grains fall on silks, they are trapped by small hairs and by the moist, sticky nature of the surface.

Kernel or caryopsis: Maize kernel is a one-seeded fruit or caryopsis. The seed enclosed within the pericarp, consist of the embryo, endosperm and remnants of the seed coats and nucellus. The pericarp is the mature ovary wall. The endosperm, beneath the pericarp consists of cells filled with starch grainules. It is surrounded by a layer of aleurone cells. The embryo consists of the plumule, radicle and scutellum.

Species of crops: Maize (*Zea mays*) us an annual plant which belongs to family *Poaceae* and *Genus Zea*. *Zea mays* L. has a normal chromosome complement of 10 pairs. It is divided into seven groups. The classification is based largely on the character of kernels (Kipps, 1959).

(1) *Zea mays indurata* or 'Flint corn': The endosperm in this type of maize kernel is soft and starchy in the centre and completely enclosed by a very hard outer layer. The kernels are usually rounded but are sometimes short and flat. Colour may be white of yellow. This is the type most commonly cultivated in India.

(2) *Zea mays indentata* or 'Dent corn': In this type of maize kernels have both hard and soft starches. The hard starch extends on the sides, and the soft starch is in the centre and extends to the top of the kernels. In the drying and shrinking of the soft starch, various forms and degrees of indentation result. This is the most common type of maize grown in U.S A.

(3) *Zea mays everta* or 'Pop corn': It possesses exceptional popping qualities. Size or the kernels is small but the endosperm is hard. When they are heated the pressure built up within the kernel suddenly result in an explosion and the grain is turned inside out.

(4) *Zea mays saccharata* or 'Sweet corn': Kernels possess a considerable amount of sugar which absorbs water, making the cells turgid on drying these cells collapse, making the grains shrivelled or wrinkled. It has sweeter taste than other corns.

(5) *Zea mays amylacea* or 'Soft corn': It possesses soft endosperms. Kernels are soft and of all colours, but white and blue are the most common. They are like flint kernels in shape.

(6) *Zea mays indurata* or 'Pod corn': The pod corns are characterised by having each kernel enclosed within a pod of husk. It is a primitive type of corn and hence of no importance.

(7) *Zea mays ceratina* Kulesh or 'Waxy corn': The endosperm of the kernel when cut or broken gives a waxy appearance. It produces the starch similar to tapioca starch for making adhesive for articles.

5.2 Comparative analysis

State wise area, production and productivity are given in Table 37. Maize is cultivated throughout the year in the country for various purposes *i.e.* grain, fodder, green cobs, *etc*. Karnataka (18%) and Andhra Pradesh (18.4%) are the major producing states followed by Maharashtra (10.3%), Rajasthan (8.7%), Bihar (7.8%), Tamil Nadu (6%) and Uttar Pradesh (5.9%). Tamil Nadu has recorded highest average yield during *kharif* 2011 (4124 Kg/ha) followed by Punjab (3566 Kg/ha), Andhra Pradesh (3148 kg/ha), Karnataka (2943 kg/ha). However, Andhra Pradesh has recorded maximum average yield during *rabi* season (6699 kg/ha) followed by Tamil Nadu (5742 kg/ha) and West Bengal (4601 kg/ha) during (2007-11). It is mentioned that the productivity of *rabi* maize is almost double as compared to *kharif* season. It has emerged as an important crop in non-traditional area/season. Cultivation during winter is becoming a common in Peninsular India (Andhra Pradesh, Karnataka and Tamil Nadu) as well as in the north-eastern plains.

Table-37: State wise normal area, production and productivity of maize (average of 2007-08 to 2011-12)

State	Area ('000 Hectares)			Production ('000 Tonnes)			Yield (kg/Hectare)		
	Kharif	***Rabi***	**Total**	***Kharif***	***Rabi***	**Total**	***Kharif***	***Rabi***	**Total**
Andhra Pradesh	498.0 (7.0)	307.8 (25.00)	805.8 (9.6)	1567.8 (10.5)	2062.0 (42.5)	3629.8 (18.4)	3148	6699	4505
Assam	19.2 (0.3)	-	19.2 (0.2)	13.9 (0.1)	-	13.9 (0.1)	723	-	723
Bihar	246.2 (3.4)	400.3 (32.6)	646.5 (7.7)	413.3 (2.8)	1126.3 (23.2)	1539.6 (7.8)	1679	2814	2381
Chhattisgarh	103.0 (14.0)	-	103.0 (1.2)	161.4 (1.1)	-	161.4 (0.8)	1567	-	1567
Gujarat	412.8 (5.8)	74.6 (6.1)	487.4 (5.8)	562.6 (3.8)	129.7 (2.7)	692.3 (3.5)	1363	1738	1420
Haryana	11.3 (0.2)	-	11.3 (0.1)	26.3 (0.2)	-	26.3 (0.1)	2334	-	2334
Himachal Pradesh	296.8 (4.2)	-	296.8 (3.5)	693.7 (5.6)	-	693.7 (3.5)	2338	-	2338
Jammu & Kashmir	310.3 (4.3)	-	310.3 (3.7)	525.5 (3.5)	-	525.5 (2.7)	1693	-	1693
Jharkhand	197.9 (2.8)	11.6 (0.9)	209.5 (2.5)	264.6 (1.8)	22.7 (0.5)	287.2 (1.5)	1337	1958	1371
Karnataka	1080.6 (15.1)	131.2 (10.7)	1211.8 (14.5)	3179.8 (21.3)	385.2 (7.9)	3565.0 (18.0)	2943	2936	2942
Madhya Pradesh	849.3 (11.9)	-	849.3 (10.1)	1132.3 (7.6)	-	1132.3 (5.7)	1333	-	1333
Maharashtra	652.2 (9.1)	126.4 (10.3)	778.6 (9.3)	1747.0 (11.7)	295.6 (6.1)	2042.6 (10.3)	2679	2339	2623
Orissa	85.3 (1.2)	3.2 (0.3)	88.5 (1.1)	185.6 (1.2)	8.0 (0.2)	193.6 (1.0)	2176	2510	2188
Punjab	140.4 (2.0)	-	140.4 (1.7)	500.6 (3.4)	-	500.6 (2.5)	3566	-	3566
Rajasthan	1076.3 (15.1)	1.7 (0.1)	1078.0 (12.9)	1724.8 (11.6)	5.0 (0.1)	1729.8 (8.7)	1603	2976	1605
Tamilnadu	164.5 (2.3)	88.6 (7.2)	253.1 (3.0)	678.2 (4.5)	508.9 (10.5)	1187.1 (6.0)	4124	5742	4691
Uttar Pradesh	755.8 (10.6)	21.6 (1.8)	777.4 (9.3)	1134.6 (7.6)	39.0 (0.8)	1173.6 (5.9)	1501	1806	1510
Uttarakhand	29.3 (0.4)	-	29.3 (0.3)	41.5 (0.3)	-	41.5 (0.2)	1418	-	1418
West Bengal	34.8 (0.5)	55.6 (4.5)	90.4 (1.1)	82.1 (0.5)	255.8 (5.3)	337.9 (1.7)	2358	4601	3737
Others	184.0 (2.6)	7.0 (0.6)	191.0 (2.3)	292.8 (2.0)	11.7 (0.2)	304.6 (1.5)	1591	1671	1066
All- India	7148.0	1229.6	8377.6	14928.4	4849.9	19778.3	2089	3994	2361

Source: DES, DAC; **NB:** Figures in parenthesis indicates % share to All India;

Area, production and yield of major maize growing countries are given in **Table-38**. Maize is one of the world's leading crops cultivated over an area of about 163 million ha with a production of about 835 million tons of grain. The United States produces 38.34% of the world's harvest. Other top producing countries include China, Brazil, Mexico, Argentina, India, Indonesia, France, Ukraine, and South Africa. The productivity of maize in these countries are 9649 kg/ha (USA), 5444 kg/ha (China), 4026 kg/ha (Brazil), 3191 kg/ha (Mexico), 6777 kg/ha (Argentina), 2365 kg/ha (India), 4205 kg/ha (Indonesia), 9368 kg/ha (France), 5081 kg/ha (Ukraine) and 4270 kg/ha (South Africa).

Table-38. Mean area, production and yield of maize in the world (2010-2011)

Sl. No.	Country	Area (Lakh hectares)	Production (Lakh tons)	Yield (kg/ha)
1	USA	331.86	3201.96	9649
2	China	313.13	1704.79	5444
3	Brazil	135.53	545.58	4026
4	Mexico	68.25	217.83	3191
5	Argentina	30.51	206.74	6777
6	India	83.63	197.78	2365
7	Indonesia	39.57	166.40	4205
8	France	16.09	150.70	9368
9	Ukraine	25.25	128.29	5081
10	South Africa	25.79	110.10	4270
11	Canada	12.17	108.41	8909
12	Italy	9.76	91.52	9374
13	Romania	23.42	80.87	3453
14	Nigeria	42.59	76.93	1806
15	Hungary	11.51	70.86	6154
16	Egypt	9.10	70.50	7743
17	Philippines	26.07	68.09	2612
18	Serbia	12.33	60.29	4889
19	Russian Federation	13.56	48.98	3613
20	Germany	4.68	45.40	9702
21	Viet Nam	11.75	45.38	3863
22	Thailand	10.85	44.87	4137
23	United Republic of Tanzania	31.77	43.00	1354
24	Turkey	5.77	41.14	7131
25	Ethiopia	17.93	39.86	2223
26	Pakistan	10.19	36.87	3618
	WORLD TOTAL	**1631.70**	**8350.49**	**5118**

Source: FAO Year book 2013.

5.3 Varietal development

Maize improvement research in India has been very dynamic since last six decades. During the pre-hybrid technology era, maize improvement/breeding started with development of local cultivars using land races as base material and their improvement through simple selection. These land races were subjected to various population improvement/ selection/ hybridization for development of composites and multi-parent crosses. These efforts have contributed very little in terms of genetic enhancement of maize in the country. The increase in productivity was 547 to 1371 kg/ha in the span of four decades from 1950-51 to 1990-91 i.e. very low (20 kg/ha/annum). After launching of the project on "Promotion of research and development efforts on hybrids in selected crops" and introduction of new Seed Policy in 1989, multi-parent crosses were given preference and continued till 2006 which resulted in increase the productivity (23 kg/ha/annum) during the period of 15 years from 1991-92 to 2005-06. Major emphasis towards development of single cross hybrids was given from 2000 onwards. Since then more than five dozen single cross hybrids have been developed and released. These hybrids have been widely adopted by farmers with the result that maize productivity attained unprecedented rate of enhancement touching 73 kg/ha/annum, which is 2-3 times higher than the productivity improvement rate witnessed between 1950 and 2000. This made maize very remunerative crop and its cultivation extended in non-traditional areas in southern India. The maize cultivation in *rabi* season is on the rise since 2000. The overall area increase in maize is to the tune of 33%. Both horizontal and vertical growth of maize has resulted in more than 80% increase in grain production since 2000. Besides this, QPM research was initiated long back during 1970's, but it gained momentum during 1990's with continuous breeding efforts on development of high yield hard endosperm modified opaque-2 maize germ plasm by International Centre for Maize and Wheat Improvement (CIMMYT) and made it availe for use in breeding programme all over the world. In India, these germplasm accessions received from CIMMYT, Mexico were tested at different centres of All India Coordinated Research Project on Maize. The list of hybrids/composites is given in **Table-39.**

Table-39: State-wise list of hybrids and composite/varieties of maize

(a) Hybrids (H) and composites (C) varieties of different maturity groups for different states for *kharif* season

States	Extra early maturity	Early maturity	Medium maturity	Late maturity
Delhi	H:Vivek 17 & 21, PMH 2	H:PAU 352, PEH 3, Parkash, X 3342	H:HM4, HM 8 10, DK 701	H:PMH 3, Buland, NK 61, Pro 311, Bio 9681, Seed Tech 2324
Punjab	H:Vivek 17& 21, PEEH 5	H:PAU 352, PEH 3, JH 3459, Parkash, PMH 2, X 3342	H:HM4, HM 8& 10, DK 701	H:PMH 3, PMH-1 , Buland, Pro 311, Bio 9681 , NK 61, Pro 311, Bio 9681, Seed Tech 2324
Haryana	H:Vivek 17 &21, PMH 2, PEEH 5	H:HHM 1,PAU 352, Pusa Early Hybrid 3, JH 3459 Parkash, X 3342	H:HM 2, HM 4,8 &10 DK 701	H:PMH 3, Buland, HM 5, NK 61, Pro 311, Bio 9681, Seed Tech 2324

Table-39: State-wise list of hybrids and composite/varieties of maize

(a) Hybrids (H) and composites (C) varieties of different maturity groups for different states for *kharif* season

States	Extra early maturity	Early maturity	Medium maturity	Late maturity
Uttar Pradesh	H:Vivek 5, 15, 17, 21 & 27 PMH 2,	H:JH 3459, Parkash,PEH 2, X 3342C: Pusa Composite 4,	H:HM 8& 10, Malviya hybrid makka 2, Bio 9637, DK 701	H:PMH 3, Buland, Pro Agro 4212, Pro 311, Bio 9681, NK 61,Seed Tech 2324
Rajasthan	H:Pratap hybrid 1, Vivek4 & 17,	H:PEHM 2, Parkash, Pro 368, X 3342C: Pratap Makka 3, Aravali Makka 1, Jawahar Makka 8,Amar, Azad Kamal, Pant Sankul Makk 3,	H:HM 10, NK 21C: Pratap Makka 5	H:Trishulata, Pro 311, Bio 9681, Seed Tech 2324
Madhya Pradesh	H:Vivek 4 & 17	H: PEHM 2, Parkash, Pro 368, X 3342C: Jawahar Makka 8, Jawahar composite 12, Amar, Azad Kamal, Pant Sankul Makk 3, Chandramani, Pratap Makka 3	H:HM 10, NK 21C: Pratap Makka 5	H:Trishulata , Pro 311, Bio 9681, Seed Tech 2324
Gujarat	H:Vivek 4 &17	PEHM 2, Parkash, Pro 368, X 3342C: Jawahar Makka 8,Pant Sankul Makka 3, Pratap Makka 3, G M 2,4 & 6 Aravali Makka 1, Narmada Moti	H:HM 10, NK 21C: Pratap Makka 5	H:Trishulata , Pro 311, Bio 9681, Seed Tech 2324C: G M 3,
Andhra Pradesh	H:Vivek 9, 15, 17& 27, PEEH 5	H:PEHM 1, PEHM 2, DHM 1, BH- 2187, Parkash, JKMH 1701, X 3342	H:HM 8& 10, DHM111,DHM117	H:DHM113,Kargil 900 M, Seed Tech 2324, Pro 311, Bio 9681, Pioneer 30 v 92, Prabal, 30 V 92,
Tamil Nadu	H:Vivek 9, 15, 17, 21& 27, PEEH 5	H:PEHM 2 , Parkash, X 3342 JKMH 1701	H:HM 8& 10, COHM 4	H:COHM 5, Prabal, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92,
Maharashtra	H:Vivek 9, 15,17, 21& 27, PEEH 5	H:PEHM 1& 2, Parkash, X 3342, JKMH 1701	H:HM 8 & 10	H:Prabal, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92,

Table-39 contd...

States	Extra early maturity	Early maturity	Medium maturity	Late maturity
Karnataka	H:Vivek 9, 15, 21& 27, PEEH 5	H:PEHM 2 , Parkash, X 3342 JKMH 1701C: NAC 6002	H:HM 8& 10	H:Nithya Shree, EH434042, DMH 1, DMH 2,Bio 9681, Prabal, Pro 311, Bio 9681, Seed Tech 2324C: NAC 6004, 30 V 92
Jammu & Kashmir	H:Vivek 15, 21, 25 &33, PEEH 5C: Pratap Kanchan 2, Shalimar KG 1 & 2,Vivek 35,and 37	H:Vivek33, Parkash, JKMH 1701, X 3342C: C 8,14 & 15	H:HM 10C: C 6	-
Uttarakhand	H:Vivek 5, 9, 21 & 25 PEEH 5 C: Pratap Kanchan 2,Vivek 35 and 37	H:Vivek hybrid 33, Vivek hybrid 23, Parkash	H:HM 10C: Bajaura Makka	-
Bihar	H:Vivek 27C: D 994	H:Parkash, X 3342C: Dewaki, Birsa Vikas Makka 2	H:HM 9, Malviya hybrid makka 2	H:Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 MC: Hemant, Suwan & Lakshmi
Jharkhand	H:Vivek 27 C: D 994,	H:Parkash, X 3342C: Dewaki, B V M 2, B M 1	H:HM 9, Malviya hybrid makka 2, DK 701	H:Pro 311, Bio 9681, Seed Tech 2324C: Suwan
Orissa	H:Vivek 27C: D 994,	H:Parkash, HIM 129,X 3342	H:HM 9, Malviya hybrid makka 2, DK 701, DMH 115, Pro 345	H:Pro 311, Bio 9681, Seed Tech 2324 , PAC 705
West Bengal	H:Vivek 27	H:Parkash, X 3342	H:Malviya hybrid Makka 2	H:Pro 311, Bio 9681, Seed Tech 2324
Himachal Pradesh	H:Vivek 15, 21& 25, PEEH 5	H:Parkash, X 3342	C: Bajaura Makka, Pratap Makka 4	Pro 311, Bio 9681, Seed Tech 2324
NEH Region	H:Vivek 21& 25, PEEH 5	H:Parkash , JKMH 1701,X 3342	C: Pratap Makka 4	H:Pro 311, Bio 9681, Seed Tech 2324C: NLD white
Chhattisgarh	H:Vivek 27	H:Parkash, X 3342	C: Pratap Makka 5	H:PEHM 1, Pioneer 30 V 92 & 30 R 26, Bio 9681, Pro 4640 & 4642,
Assam	–	H:Parkash, X 3342	DK 701C: Pratap Makka 4	C: Vijay ,NLD white,

(b) List of hybrids for different states for *rabi* season

There is large number of hybrids of late maturity recommended for *kharif* season and the same can be cultivated during *rabi* also. Even majority of these hybrids listed below are not released for *rabi* season.

3b. Hybrids of maize for different states for *rabi* season

States	*Rabi* season hybrid
Delhi	PMH 3, Buland, NK 61, Pro 311, Bio 9681, Seed Tech 2324,HM11,HM8
Punjab	PMH 3, PMH-1 , Buland, Sheetal , Pro 311, Bio 9681 , NK 61, Pro 311, Bio 9681, Seed Tech 2324,HM11,HM8
Haryana	PMH 3, Buland, HM 5, NK 61, Pro 311, Bio 9681, Seed Tech 2324,HM11,HM2,HM1,HM8
Uttar Pradesh	PMH 3, Buland, Pro Agro 4212,Pro 311, Bio 9681, NK 61,Seed Tech 2324,HM8
Rajasthan	Pro 311, Bio 9681, Seed Tech 2324, HM8
M.P.	Pro 311, Bio 9681, Seed Tech 2324
Gujarat	Pro 311, Bio 9681, Seed Tech 2324
Andhra Pradesh	The late maturing hybrids of *Kharif* e.g. Kargil 900 M, Seed Tech 2324, Pro 311, Bio 9681, Pioneer 30 v 92, Prabal, 30 V 92, 900 M
Tamil Nadu	COHM 5, Prabal , Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 M
Maharashtra	Prabal, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 M
Karnataka	Nithya Shree, DMH 1, DMH 2, 900 M, Bio 9681, Prabal, Pro 311, Bio 9681, Seed Tech 2324
Bihar	Rajendra Hybrid 2, Rajendra Hybrid 1, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 M
Jharkhand	Pro 311, Bio 9681, Seed Tech 2324
Orissa	Pro 311, Bio 9681, Seed Tech 2324 , PAC 705
West Bengal	Pro 311, Bio 9681, Seed Tech 2324
Himachal Pradesh	Pro 311, Bio 9681, Seed Tech 2324
NEH Region	Pro 311, Bio 9681, Seed Tech 2324
Chhattisgarh	Pioneer 30 V 92 & 30 R 26, Bio 9681, Pro 4640 & 4643, 900 M

(c) Hybrids for different states for *spring* season

Not recommended but early to medium maturity hybrids in spring can cultivated during this season.

Critical gap in availability of seed of recommended varieties/hybrids

(i) a variety recommended for a state is adequately available but not used;

(ii) a variety recommended for a state is inadequately available but it is in great demand;

(iii) a variety recommended but neither produced nor in demand.

Yield potential and gap in maize during *kharif* season

Frontline Demonstrations (FLDs) have been organized by the Directorate of Maize Research, New Delhi over an area of 11025.65 ha during 2008-09 to 2012-13 through its centers located in Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Nagaland, Odisha, Punjab, Rajasthan, Sikkim, Tamil Nadu, Tripura, Uttar Pradesh, Uttarakhand and West Bengal on improved production technology of maize. The state wise progress of FLDs of maize is given in **Table-40**.

Table-40. The state wise progress of FLDs of maize for *kharif* season

Sl. No.	State	Year wise area (ha) under FLD					
		2008	2009	2010	2011	2012	Total
1	Andhra Pradesh	80.00	30.40	123.60	60.00	72.00	366.00
2	Arunachal Pradesh	0	0	0	14.40	0	14.40
3	Assam	0	24.00	6.00	31.80	0	61.80
4	Bihar	118.42	150.0	156.40	264.40	111.40	800.62
5	Chhattisgarh	150.00	210.00	0	140.00	14.00	514.00
6	Delhi	22.80	0	36.40	0	0.80	60.00
7	Gujarat	58.00	163.20	85.20	71.60	118.20	496.20
8	Haryana	0	0	0	79.60	65.60	145.20
9	Himachal Pradesh	287.20	282.00	230.80	332.00	141.04	1273.04
10	Jammu & Kashmir	47.60	413.20	149.20	124.00	116.07	850.07
11	Jharkhand	36.00	15.10	13.00	38.56	35.62	138.28
12	Karnataka	193.60	88.00	70.00	140.00	120.00	611.60
13	Madhya Pradesh	72.80	107.60	42.00	120.00	175.60	518.00
14	Maharashtra	66.40	74.80	98.00	95.20	127.60	462.00
15	Manipur	0	0	0	14.00	3.00	17.00
16	Meghalaya	0	0	0	24.50	7.00	31.50
17	Nagaland	0	0	0	9.00	5.00	14.00
18	Odisha	106.00	0	80.00	100.00	64.00	350.00
19	Punjab	60.00	0	0	94.00	37.60	191.60
20	Rajasthan	180.24	211.20	317.20	264.00	180.80	1153.44
21	Sikkim	0	0	0	90.90	0	90.90
22	Tamil Nadu	100.00	80.00	80.00	60.80	100.80	421.60
23	Tripura	0	0	0	6.18	0	6.18
24	Uttar Pradesh	612.00	734.60	392.00	266.72	299.28	2304.60
25	Uttarakhand	0	0	0	24.92	28.70	53.62
26	West Bengal	0	0	44.00	20.00	16.00	80.00
	Total	2191.06	2584.10	1923.80	2486.58	1840.11	11025.65

Table-41: Yield performance of FLDs of maize during *kharif* season

Sl. No.	State	Plot	Year-wise yield (Kg/ha)					
			2008	2009	2010	2011	2012	Average
1	Andhra Pradesh	FLD	4214	6120	5341	3980	3834	4698
		SAY	3147	1986	3730	2812	4143	3164
		% Yield gap over SAY						48
2	Arunachal Pradesh	FLD	-	-	-	5425	-	5425
		SAY				1434	-	1434
		% Yield gap over SAY						278
3	Assam	FLD	-	3971	3698	4672	-	4114
		SAY	-	726	722	719	-	722
		% Yield gap over SAY						469
4	Bihar	FLD	4110	4034	4593	3628	4239	4121
		SAY	1518	1773	1806	2358	2358	1963
		% Yield gap over SAY						110
5	Chhattisgarh	FLD	4370	4429	-	4439	3890	4282
		SAY	1402	1399	-	1654	1936	1598
		% Yield gap over SAY						168
6	Delhi	FLD	1519	-	1372	-	6200	3030
		SAY	1000					1000
		% Yield gap over SAY						203
7	Gujarat	FLD	3267	2928	3368	2741	3515	3164
		SAY	1439	964	1636	1393	1676	1422
		% Yield gap over SAY						123
8	Haryana	FLD	-	-	-	4926	2378	3652
		SAY	-	-	-	2667	2556	2612
		% Yield gap over SAY						40
9	Himachal Pradesh	FLD	3567	3659	3808	3598	3868	3700
		SAY	2273	1839	2263	2432	2242	2210
		%Yield gap over SAY						67
10	Jammu & Kashmir	FLD	4555	2728	4673	5055	4421	4286
		SAY	2005	1566	1712	1608	1648	1708
		% Yield gap over SAY						151
11	Jharkhand	FLD	3550	2630	4005	2173	4052	3282
		SAY	1346	1100	1181	1473	1671	1354
		% Yield gap over SAY						142
12	Karnataka	FLD	6435	5310	5534	6358	6828	6093
		SAY	2821	2415	3515	3022	2569	2868
		% Yield gap over SAY						112
13	Madhya Pradesh	FLD	3251	4022	3438	4134	3696	3708
		SAY	1361	1256	1266	1492	1790	1433
		% Yield gap over SAY						159

Table-41 contd…

Sl. No.	State	Plot	Year-wise yield (Kg/ha)					
			2008	2009	2010	2011	2012	Average
14	Maharashtra	FLD	4452	4734	4231	4757	4939	4623
		SAY	2405	2275	3022	2890	2319	2582
		% Yield gap over SAY						79
15	Manipur	FLD	-	-	-	3414	2445	2930
		SAY	-	-	-	1768		1768
		% Yield gap over SAY						66
16	Meghalaya	FLD	-	-	-	3262	3441	3352
		SAY	-	-	-	1529		1529
		% Yield gap over SAY						119
17	Nagaland	FLD	-	-	-	3014	5200	4107
		SAY	-	-	-	1960		1960
		% Yield gap over SAY						110
18	Odisha	FLD	4358	-	4795	4387	5179	4680
		SAY	1986	-	2540	2046	2392	2241
		% Yield gap over SAY						109
19	Punjab	FL D	4250	-	-	4764	4563	4526
		SAY	3404	-	-	3984	3682	3690
		% Yield gap over SAY						23
20	Rajasthan	FLD	3124	2773	3301	3259	3800	3251
		SAY	1737	1044	1796	1583	1763	1585
		% Yield gap over SAY						105
21	Sikkim	FLD	-	-	-	4496	-	4496
		SAY	-	-	-	1657	-	1657
		% Yield gap over SAY						171
22	Tamil Nadu	FLD	5469	4950	6696	7748	7776	6528
		SAY	3668	4301	3858	5682	3941	4290
		% Yield gap over SAY						52
23	Tripura	FLD	-	-	-	2790	-	2790
		SAY	-	-	-	1353		1353
		% Yield gap over SAY						106
24	Uttar Pradesh	FLD	4359	4185	4137	4826	4940	4489
		SAY	1495	1456	1468	1654	1654	1545
		% Yield gap over SAY						191
25	Uttrakhand	FLD	-	-	-	6359	2549	4454
		SAY	-	-	-	1464	1429	1447
		% Yield gap over SAY						208
26	West Bengal	FLD	-	-	4557	2326	2884	3256
		SAY	-	-	2588	2270	2384	2414
		% Yield gap over SAY						35

The above data reveals largest yield gap over State average yield in Assam (469%) followed by Arunachal Pradesh (278%), Uttarakhand (208%), Delhi (203%), Uttar Pradesh (191%), Sikkim (171%), Chhattisgarh (168%), Madhya Pradesh (159%), J & K (151%) with least gap in Punjab (23%), West Bengal (35%), Haryana (40%), Andhra Pradesh (48%), Tamil Nadu (52%) Himachal Pradesh (67%) and Maharashtra (79%) over SAY.

Yield potential and gap in maize during *rabi* season

FLDs have been organized by the Directorate of Maize Research, New Delhi over an area of 5388.70 ha during 2008-09 to 2012-13 through its centers located in Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Delhi, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Odisha, Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh on improved production technology of maize. The state wise progress of FLDs of maize is given in **Table-42**.

Table-42: The state wise progress of FLDs of maize for *rabi* season

Sl. No.	State	Year wise area (ha) under FLD					
		2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Total
1	Andhra Pradesh	61.20	148.00	192.00	121.80	14.00	537.00
2	Arunachal Pradesh	0	0	0	0	4.00	4.00
3	Assam	0	0	0	1.20	0	1.20
4	Bihar	173.60	309.10	228.70	373.40	285.66	1370.46
5	Chhattisgarh	55.20	0	40.0	96.80	60.80	252.80
6	Delhi	0	0	0	0	7.20	7.20
7	Gujarat	0	56.00	49.20	45.60	99.64	250.44
8	Haryana	0	0	0	20.00	40.00	60.00
9	Himachal Pradesh	0	40.00	0	0	0	40.00
10	Jharkhand	0	0	3.80	0	0	3.80
11	Karnataka	50.00	160.00	90.00	0	0	300.00
12	Madhya Pradesh	0	5.60	30.40	54.40	88.80	179.20
13	Maharashtra	60.00	92.80	10.00	22.80	16.00	201.60
14	Manipur	0	0	0	0	7.20	7.20
15	Odisha	0	0	40.00	10.00	80.00	130.00
16	Punjab	10.00	4.00	0	0	0	14.00
17	Rajasthan	39.00	30.80	19.20	0	24.00	113.00
18	Tamil Nadu	6.00	140.00	80.00	80.00	51.60	357.60
19	Uttar Pradesh	321.20	428.80	154.80	430.40	224.00	1559.20
	Total	776.20	1415.10	938.10	1256.40	1002.90	5388.70

Table-43: Yield performance of FLDs of maize during *rabi* season

Sl. No.	State	Plot	Year wise yield in kg/ha					
			2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Average
1	Andhra Pradesh	FLD	5539	6729	7233	6743	7527	6754
		SAY	5543	7302	6281	7615	6502	6649
		% Yield gap over SAY						2
2	Arunachal Pradesh	FLD	-	-	-	-	2570	2570
		SAY	-	-	-	-	1736	1736
		% Yield gap over SAY						48
3	Assam	FLD	-	-	-	7167	-	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-
4	Bihar	FLD	5837	5718	5959	5805	6857	6035
		SAY	2766	3394	2660	2467	2404	2738
		% Yield gap over SAY						120
5	Chhattisgarh	FLD	-	-	4257	4427	4488	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-
6	Delhi	FLD	-	-	-	-	1600	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-
7	Gujarat	FLD	4507	4719	3433	2819	4076	4889
		SAY	-	1700	1593	1645	1915	1713
		% Yield gap over SAY						185
8	Haryana	FLD	-	-	-	1640	4279	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-
9	Himachal Pradesh	FLD	-	5631	-	-	-	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-
10	Jharkhand	FLD	-	-	5518	-	-	5518
		SAY	-	-	1858	-	-	1858
		% Yield gap over SAY						197
11	Karnataka	FLD	6319	5595	6486	-	-	6133
		SAY	3231	2861	2500	-	-	2864
		% Yield gap over SAY						114
12	Madhya Pradesh	FLD	-	5400	3237	5199	4709	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-

Table-43 contd...

Sl. No.	State	Plot	Year wise yield in kg/ha					
			2007-2008	2008-2009	2009-2010	2010-2011	2011-2012	Average
13	Maharashtra	FLD	5125	5279	6690	6743	6887	6145
		SAY	2426	2257	2455	2456	2110	2341
		% Yield gap over SAY						163
14	Manipur	FLD	-	-	-	-	3837	3837
		SAY	-	-	-	-	2165	2165
		% Yield gap over SAY						77
15	Odisha	FLD	-	-	4364	3470	5207	4347
		SAY	-	-	2247	2778	2496	2507
		% Yield gap over SAY						73
16	Punjab	FLD	8370	6644	-	-	-	-
		SAY	-	-	-	-	-	-
		% Yield gap over SAY						-
17	Rajasthan	FLD	8926	4525	5465	-	6826	6436
		SAY	1667	1429	1429	-	3434	1990
		% Yield gap over SAY						223
18	Tamil Nadu	FLD	6039	5568	5297	6772	7658	6267
		SAY	5091	5763	5431	5452	6649	5677
		% Yield gap over SAY						10
19	Uttar Pradesh	FLD	6982	5928	4760	5605	5777	5810
		SAY	1616	1621	2800	2667	1810	2103
		% Yield gap over SAY						176

The major yield gap is reported in Rajasthan (223%), Jharkhand (197%), Gujarat (185%), Uttar Pradesh (176%), Maharashtra (163%), Bihar (120%) with least gap in Andhra Pradesh (2%), Arunachal Pradesh (48%), Odisha (73%) over farmer practice (**Table-43**).

Table-44: The state wise progress of FLDs of maize for summer season

Sl. No.	State	Year wise area (ha) under FLD					
		2008	2009	2010	2011	2012	Total
1	Assam	4.00	0	0	0	0	4.00
2	Bihar	0	96.40	40.00	29.20	31.90	197.50
3	Chhattisgarh	0	0	0	40.00	0	40.00
4	Delhi	0	0	20.00	0	0	20.00
5	Haryana	0	0	0	76.00	55.20	131.20
6	Jammu & Kashmir	0	0	0	0.40	0	0.40
7	Jharkhand	0	0	0	0.40	20.12	20.52
8	Karnataka	0	20.00	0	43.60	0	63.60
9	Madhya Pradesh	40.00	6.00	22.00	0	0	68.00
10	Maharashtra	0	0	12.00	0	0	12.00
11	Manipur	0	0	0	0	5.00	5.00
12	Meghalaya	0	0	0	0	7.20	7.20
13	Odisha	0	0	0	20.00	0	20.00
14	Punjab	24.00	0	46.56	0	64.40	134.96
15	Tamil Nadu	0	0	0	16.00	0	16.00
16	Uttar Pradesh	74.00	122.00	52.00	103.20	123.60	474.80
	Total	142.00	244.40	192.56	328.80	307.42	1215.18

Table-45: Yield performance of FLDs of maize during summer season

Sl. No.	State	Plot	Year wise area (ha) under FLD					
			2008	2009	2010	2011	2012	Average
1	Assam	FLD	3187	-	-	-	-	3187
2	Bihar	FLD	-	4768	4322	3853	5045	4497
3	Chhattisgarh	FLD	-	-	-	3740	-	3740
4	Delhi	FLD	-	-	2050	-	-	2050
5	Haryana	FLD	-	-	-	1517	4725	3121
6	Jammu & Kashmir	FLD	-	-	-	1515	-	1515
7	Jharkhand	FLD	-	-	-	1512	3255	3384
8	Karnataka	FLD	-	5052	-	6462	-	5757
		SAY	-	3143	-	3323	-	3233
	% Yield gap over SAY							78
9	Madhya Pradesh	FLD	3105	868	522	-	-	1498
10	Maharashtra	FLD	-	-	4487	-	-	4487
11	Manipur	FLD	-	-	-	-	4100	4100
12	Meghalaya	FLD	-	-	-	-	3533	3533
13	Odisha	FLD	-	-	-	2145	-	2145
14	Punjab	FLD	6326	-	5041	-	6116	5828
15	Tamil Nadu	FLD	-	-	-	5295	-	5295
16	Uttar Pradesh	FLD	5730	4523	4277	4116	4104	4450

5.4 Climatic requirement

Maize is a warm weather crop. It grows from sea level to 3000 meter altitudes. It can be grown under diverse conditions. It is grown in many parts of the country throughout the year. *Kharif* (monsoon) season is the main growing season in northern India. In the south, however, maize may be sown any time from April to November, as the climate is warm even in the winter. Maize requires considerable moisture and warmth from germination to flowering. It is warm-weather crop and requires high day and night temperature for germination as well as the growth. The optimum temperature for germination is 18-23°C. The temperature below than 12.8°C retards germination. The temperature during the growing period varies from 10 to 45 °C. For rest of the growth period, the optimum temperature is 28 °C. Maize plants are sensitive to very high and low temperature at tasseling stage. Extremely high temperature and low humidity during flowering damage the foliage, desiccates the pollen and interferes with proper pollination, resulting in poor grain formation. Fifty to seventy-five centimeter of well distributed rain is conducive to proper growth. Maize is very sensitive to stagnant water, particularly during its early and cob development stage of the crop.

Impact of rise in temperature on yield of the crop: Corn yield may be reduced due to high temperature (35°C and higher) with low humidity during pollination. High temperatures during this time can cause damage to pollination if plants are under drought stress. During moisture stress, especially at low relative humidity, high temperatures can desiccate silks and damage or kill pollen (tassel blasting/firing). Pollination will not be affected by high temperatures if there is adequate moisture in the soil, because pollen shed usually occurs during morning hours. At the higher temperature, maize roots find it increasingly difficult to absorb water to cope up with the transpiration requirement, which also affect the corn growth.

Climatic resilience of the crop: Under the changing climatic scenario in the country, maize has been emerging as one of the potential crops that addresses several issues like temperature rise, water scarcity *etc*. Maize being a photo-insensitive crop, has better options for adaptation and mitigating the effects of sudden temperature rise during *rabi* season, where wheat productivity is affected due to terminal heat at grain filling stage. Maize is also emerging as a potential as well as profitable crop in the areas with water scarcity and lowering of water table.

5.5 Status and scope for transgenic and genomics

Globally, among all crops, maize has highest number of transgenic events approved for cultivation. Today, 35% of total global maize acreage is under transgenic cultivars and this proportion is rapidly increasing every year. Herbicide tolerance and insect resistance are widely cultivated traits among farmers. Other traits like drought tolerance, high lysine, enhanced ethanol potential, improved feed quality and superior hybrid seed production system are already available to maize growing farmers of many countries for cultivation. A number of other path-breaking traits are in research pipeline. In India, transgenic maize cultivars with herbicide tolerance and insect resistance trait are under advanced field trials. There is a great scope for early commercialization of superior transgenic cultivars in India to keep Indian maize farmer globally competitive. In addition to transgenic, the pace of genomics research in maize has also accelerated greatly since 2009, when complete maize genome was cracked. Maize breeders in most advanced laboratories are now routinely using whole genome selections in the breeding schemes for rapid genetic gain. There is a lot of scope for utilizing such tools for Indian maize improvement programme as well.

5.6 Seed Scenario

Table-46: State-wise SRR (%)of maize during 2006 to 2008

Sl. No.	State/ Cultivar	2006	2007	2008	2009	2010	2011	2012
1.	**Andhra Pradesh**							
	Variet	87	0	-	-	-	-	-
	Hybrids	100	100	100	100	100	100	100
2.	**Karnataka**							
	Variety	0	-	-	-	-	-	-
	Hybrids	100	100	100	100	100	100	100
3.	**Tamil Nadu**							
	Variety	2	1	70	97.71	83.13	-	-
	Hybrids	-	-	-	-	-	97.87	76.48
4.	**Gujarat**							
	Variety	-	0	-	-	-	-	-
	Hybrids	100	100	100	100	100	100	100
5.	**Maharashtra**							
	Variety	75	60	89	90.89	90.51	93.93	94.48
	Hybrids	100	-	-	-	-	-	-
6.	**Rajasthan**							
	Variety	19.86	25.20	42.49	44.29	40.99	52.66	44.00
	Hybrids	-	-	-	-	-	-	-
7.	**Madhya Pradesh**							
	Variety	12.94	10.94	19.13	21.23	35.39	47.55	49.78
	Hybrids	-	-	-	-	-	-	-
8.	**Uttar Pradesh**							
	Variety	19.85	19.50	21.44	21.66	37.66	30.48	30.00
	Hybrids	-	-	-	-	-	-	-
9.	**Punjab**							
	Variety	95	95	91	97.71	99.08	99.18	100
	Hybrids	-	-	-	-	-	-	-
10.	**Himachal Pradesh**							
	Variety	0.07	0.05	58	49.32	50.51	33.78	33.25
	Hybrids	100	100	-	-	-	-	-
11.	**Jammu & Kashmir**							
	Variety	5.66	7.51	13.41	10.13	11.21	18.16	15.49
	Hybrids							
12.	**Odisha**							
	Variety	1.37	2.07	1.81	3.63	20.87	13.2	18.75
	Hybrids	-	-	-	-	-	-	-
13.	**West Bengal**							
	Variety	22	23	24	26.02	28	29.04	30
	Hybrids	-	-	-	-	-	-	-

Sl. No.	State/ Cultivar	2006	2007	2008	2009	2010	2011	2012
14.	**Bihar**							
	Variety	60	75	57	64.39	81.05	100	82
	Hybrids	-	-	-	-	-	-	-
15.	**Chhattisgarh**							
	Variety	11	11.5	12.07	16.13	18.03	21.23	27.7
	Hybrids	-	-	-	-	-	-	-
16.	**Assam**							
	Variety	0.62	0.06	15	37.57	51.3	22.12	8.78
	Hybrids	-	-	-	-	-	-	-
17.	**Uttarakhand**							
	Variety	3.35	5.06	10	3.04	10.44	1.82	2.98
	Hybrids	-	-	-	-	-	-	-
18	**Jharkhand**							
	Variety	7	10.8	9	19.18	15.71	7.27	14.27
	Hybrids	-	-	-	-	-	-	100
	ALL INDIA							
	Variety	43.78	44.24	48.48	46.85	54.09	52.65	54.22
	Hybrids	-	-	-	-	-	-	-

Source: Seed net India portal.

5.7 Recommended package of practices

The recommended various packages of practices of maize for different seasons are mentioned in **Table-47**.

Table-47: Recommended package of practices

S.No.	Operation	Maize
1.	**Time of sowing**	
	Kharif North-western hills North-eastern hills Peninsular region Indo- gangetic plains	April to early May First fortnight of March May to June Last week of June to first fortnight of July
	Rabi	Last week of October for inter-cropping and up to 15th of November for sole crop
	Spring	First week of February
2.	Method of sowing · ● Flat bed under low rainfall areas· ● Ridge planting under high rainfall areas	

S.No.	Operation	Maize			
3.	**Seed**				
	Seed Rate	20-22 kg/ha			
	Plant to plant distance	*Kharif* season: 60-75 cm X 20 cm (irrigated); 75 cm x 25 cm (rainfed) *Rabi* season: 60cm X 18-20 cm			
	Ideal plant population/ha	*Kharif* season: 66666 to 83,333 (irrigated); 53000 (rain fed*Rabi* season: 83,333-90000			
	Seed treatment				
	Fungicides (Name & Dose)	Thiram/ Captan @ 2-2.5g/kg of seed			
	Bio-fertilizer (Name & Dose)	*Azotobacter* or *Azospirillium* @ 500g/ha for seed treatment			
4.	Fertilizer doses (kg/ha)				
	Kharif/spring	Split application of urea (Stage and % of urea)			
	Hybrid (Medium and Late): 150:75:50 kg/ha (N:P_2O_5: K_2O) Hybrid (early) and composites: 100:40:25 kg/ha (N:P_2O_5: K_2O)	Basal 15%	Knee high 40%	Flowering 35%	Grain filling 10%
	SSP/DAP for phosphorus (P_2O_5)	Full amount as basal			
	MOP for potash (K_2O)	Full amount as basal			
	Zinc sulphate =25 kg/ha	Full amount as basal			
	Bio-fertilizers	*Azospirillium/Azotobacter*			
	Manures	10 t FYM/ha			
	Rabi				
	Hybrid (Medium and Late): 180:80:60 kg/ha (N:P_2O_5: K_2O)	Split application of urea (Stage and % of urea) Basal 15%	 Knee high 40%	 Flowering 35%	 Grain filling 10%
	SSP/DAP for phosphorus (P_2O_5)	Full amount as basal			
	MOP for potash (K_2O)	Full amount as basal			
	Zinc sulphate=25 kg/ha	Full amount as basal			
	Bio-fertilizers (Name and Dose)	*Azospirillium/Azotobacter* 500g/ha			
	Manures	10 t FYM/ha			

S.No.	Operation	Maize	
5	**Weed control**		
	Name of major weeds		
	Grassy Weeds: *Echinochloa crusgalli* *Acrachne racemosa* *Digitaria sanguinalis* *Dactyloctenium aegyptium* *Paspalum dialatum* *Cynodon dactylon*	Broad leaved weeds: *Trianthema portulacastrum* *Trianthema monogyna* *Digera arvensis* *Commelina benghalensis* *Phyllanthus niruri* *Xanthium strumarium* *Boerhaavia diffusa* *Oxalis corniculata* *Parthenium hysterophorus*	Sedges: *Cyperus rotundus* *Cyperus esculentus* *Cyperus iria*
	Control measures : Application of weedicide and one hand weeding at 30 days stage		
	Name of weedicide	Atrazine	
	Dose	1.0-1.5 kg a.i/ ha	
	Time of Application	Pre emergence application	
	Method of application	Spray in 600 l/ha of solution	

6 Major Diseases/pest

a.	Diseases	Turcicum Leaf Blight	Maydis Leaf Blight	Polysora rust	Common rust	Banded Leaf Sheath Blight	Brown stripe downy mildew	Sorghum downy mildew
	Control Measures	1. Seed treatment 2. Foliar spray at first appearance of disease.						
	Name of Fungicide	1. Thiram/Captan 2. Zineb/Maneb		1. Thiram/Captan 2. Zineb/Maneb		1. Thiram/Captan 2. Rhizolex 50 WP	1. Metalaxyl (Ridomil 25 WP, Apron 35 SD) 2. Metalaxyl (Ridomil Apron 35 FN)	
	Doses	1. 2 -2.5 g/kg of seed 2. 2- 4 g/l of water at 8-10 days interval		1. 2 -2.5 g/kg of seed 2. 2-2.5g/l of water at 15 days interval		1. 2.5 g/kg of seed 2. 1 g/l of water at 30-40 days old crop	1. 2.5 g/kg of seed 2. 2.5 g/l of water	
	IPM	• Crop rotation • Ploughing down of crop debris • Destroy infected crop debris • Use resistant varieties				• Stripping of 2 lower leaves along with leaf sheath. • Crop rotation • Ploughing down of crop debris • Destroy infected crop debris	• Crop rotation • Ploughing down of crop debris • Use resistant varieties	• Crop rotation • Ploughing down of crop debris • Use resistant varieties • Destroy infected crop debris and sorghum weeds. • Avoid maize-sorghum crop rotation in field

6 Major Diseases/pest

b.	Diseases	Rajasthan downy mildew	Brown spot	Pythium stalk rot	Bacterial stalk rot	Post Flowering Stalk Rots
	Control Measures	1. Seed treatment 2. Foliar spray at first appearance of disease.		Soil drenching at base of the plant at first appearance of disease.	1. Soil drenching	1. Seed treatment
	Name of Fungicide	1. Metalaxyl (Ridomil 25 WP, Apron 35 SD) 2. Metalaxyl (Ridomil Apron 35 FN)	1. Zineb/ Maneb	1. Captan 75%	1. Bleaching powder containing 33% chlorine	2. Thiram/Captan
	Doses	1. 2.5g/kg of seed 2. 2.5g/l of water	1. 2 -2.5 g/l of water at 8-10 days interval	1. 12 g/100 l of water	1. 10 kg/ha at pre flowering stage	1. 2.5g/kg of seed
	IPM	• Crop rotation • Ploughing down of crop debris • Destroy infected crop debris • Use resistant varieties		• Good field drainage • Crop rotation • Ploughing down of crop debris • Destroy infected crop debris • Use resistant varieties	• Avoidance of water logging. • Field should have proper drainage. • Planting of the crop on ridges rather than flat soil. • Crop rotation • Ploughing down of crop debris	• Crop rotation and ploughing down of crop debris • Use resistant varieties with good stalk strength. • Avoid water stress at flowering time. Apply potash @ 80 kg/ha in endemic areas. • Use *Trichoderma* formulation after mixing with FYM @ 10 g/kg and incubate for 10 days covered with wet gunny bags. This mixture should be used in furrows before sowing.

S. No.	Operation					
6c.	Major pests					
Name of pest	Maize stem borer *(Chilo partellus)*	Pink stem borer *(Sesamia inferens)*	Sorghum shoot fly *(Atherigona spp.)*	Cut Worm (*Agrotis ipsilon*)	Pyrilla *(Pyrilla perpusilla)*	Termites *(Microtermes obesi)*
Control measures						
Method	1. Seed treatment 2. Foliar spray 3. Granule application		1. Seed treatment 2. Granule application	1. Seed treatment 2. Foliar spray 3. Granule application	1. Foliar spray	1. Foliar spray
Name of the insecticide	1. Imidacloprid 2. Carbaryl 50 WP 3. Carbofuran 3G		1. Imidacloprid 2. Carbofuran 3G	1. Imidacloprid 2. Carbaryl 50 WP 3. Carbofuran 3G	1. Rogor/ Metasystox 30EC	1. Chlorpyriphos 20EC
Dose	1. Seed treatment @ 6 ml/kg. 2. 2.35 g/l of water 3. 2-3 granules/plant		1. Seed treatment 6 ml/ kg 2. 2-3 granules / plant	1. Seed treatment @ 6 ml/kg2. 2. 35 g/l of water 3. 2-3 granules / plant	1. 2-3 ml/l of water	1. 3-5 ml/l of water
IPM	• Use resistant/hybrids/composites • Use only well decomposed FYM to reduce termite attack • Follow proper water management practices • Collect mechanically and destroy the dead hearts to reduce further infestation of stem borer. • Release *Trichogramma chilonis* @ 1,60,000 /ha. on 7 and 15 days old crop. • Conserve biocontrol agents *Trichogramma chilonis*, *Cotesia flavipes*, Carabids, *Coccinellids*, *Chrysoperla*, Spiders and Wasps *etc*. by reducing the use of chemical pesticides. • Need based and judicious application of pesticides is an important components of IPM, hence apply the above cited insecticides at the recommended dose and time.					

S.No.	Operation	Maize
7.	Harvesting & Threshing	
	Time	
	Kharif	October end
	Rabi	Mid May onwards
	Spring	Third week of June
	Method	Manual
	Threshing	Manually or by sheller
8.	**Any innovative technology/ITK adopted in the crop** **Seed Storage in Maharashtra:** *Neem* leaves are used to store the sundried maize seed. Seed is also stored in bamboo box applied with the mixture of dung, mud and water on both sides of the box. Before placing the box ash is spread on floor. **Protection from pest in Maharashtra:** *Neem* fruit and leaves are crushed and mixed in water. Thereafter dung and jaggeries are added; and after 3-4 days, this mixture is filtered and used for spraying to protect the crop from pest and diseases. This is also used as soil application through mixing with irrigation water. **Storage of seed in Jharkhand:** *Chiraitha* plant is found in Jungle which is similar to *Neem*. The leaves are dried and mixed with maize seed and stored for one season. The leaves of *Sariya* plant are dried and mixed with maize seed and stored. **Storage of seed in Madhya Prades** Store seed in mud pots by mixing it with *Neem* leaves. **Protection from pest in Punjab:** In cow dung and urine, *chaas, neela thotha* and *Neem* leaves are added. The mixture is sprayed on the crop which protects from insect and diseases. **Protection from pest in Chhattisgar** The powder of *Neem* leaves and fruits is boiled in water and after filtering it is over night. This mixture is sprayed it to protect from pest and diseases.	

Improved package of practices of *kharif* maize and *rabi* maize in detail are given in **Annexure-*I* *and II*.**

5.8 Cropping Systems

Maize has wide adaptability and compatibility under diverse soil and climatic conditions and hence it is cultivated in sequence with different crops under various agro-ecologies of the country. Hence, it is considered as one of the potential driver of crop diversification under different situation. Among different maize based cropping systems, maize-wheat ranks 1st mainly concentrated in rain fed ecologies. Maize-wheat is the 3rd most important cropping systems after rice-wheat and rice-rice. The other major maize systems in India are maize-mustard, maize-chickpea, maize-maize, cotton-maize *etc*. Recently, due to changing scenario of natural resource base, rice-maize has emerged a potential maize based cropping system in peninsular and eastern India. In *peri*-urban interface, maize based high value intercropping systems are also gaining importance due to market driven farming. Further, maize has compatibility with several crops of different growth habit that led to development of various intercropping systems. Based on the studies carried out under various soil and climatic conditions under All India Coordinated Research Project the following maize based cropping systems were recommended in Table-48 and 49.

Table-48. Maize based sequential cropping systems in different ago-climatic zones of India

Agro-climatic region	Cropping system	
	Irrigated	**Rainfed**
Western Himalayan Region	Maize-wheat Maize-potato-wheat Maize-wheat-mungbean Maize-mustard Maize-sugarcane	Maize-mustard Maize-legumes
Eastern Himalayan Region	Summer rice-maize-mustard Maize-maize Maize-maize-legumes	Sesame-Rice+maize
Lower Gangetic Plain region	Autumn rice-maize Jute-rice-maize	Rice-maize
Middle Gangetic Plain region	Maize-potato-wheat-mungbean Maize-wheat Maize-wheat-mungbean Maize-wheat-urdbean Maize-sugarcane-mungbean	Maize-wheat
Upper Gangetic Plain region	Maize-wheat Maize-wheat-mungbean Maize-potato-wheat Maize-potato-sunflower Maize-potato-onion Maize-potato-sugarcane-ratoon Rice-potato-maize	Maize-wheat Maize-barley Maize-safflower
Trans Gangetic Plain region	Maize-wheat Maize-wheat-mungbean Maize-potato-wheat Maize-potato-sunflower Maize-potato-onion Mungbean-maize-*toria*-wheat Maize-potato-mungbean	Maize-wheat
Eastern plateau and hills region	Maize-groundnut-vegetables Maize-wheat-vegetables	Rice-potato-maize Jute-maize-cowpea
Central plateau and hills region	Maize-wheat	Maize-groundnut
Western plateau and hills region	Sugarcane + Maize	-
Southern plateau and hills region	Rice-maize Maize-rice	Sorghum-maize Maize-sorghum-Pulses Maize-potato-groundnut

Agro-climatic region	Cropping system	Rainfed
	Irrigated	
East coast plain and hills region	Rice-maize-pearl millet Maize-rice Rice-maize Rice-rice-maize	Maize-maize-pearl millet Rice-maize + cowpea
West coast plain and hills region	Maize-pulses Rice-maize	Rice-maize Groundnut-maize
Gujrat plains and hills region	Maize-wheat	Rice-maize
Western dry region	Maize-mustard Maize-chickpea	Maize+legumes
Island region	Rice-maize	Maize-rice Rice-maize + cowpea Rice-maize-urdbean Rice-rice-maize

Table-49: Maize based intercropping systems

Sl. No.	State	Crops Recommended for Intercropping
1	North-Western Region (Punjab, Haryana, Delhi & Western U.P.)	Pea, Rajmah
2	North-Eastern Region (Bihar, Eastern U.P., Orissa, West Bengal & NE Region)	Pea, Rajmah, Potato, Bakla and Onion.
3	Southern Region (Maharashtra, Andhra Pradesh, Karnataka and Tamilnadu)	Fenugreek, Coriander, Sunflower
4	Central Region (Rajasthan, M.P. and Gujarat)	Pea, Onion, Garlic and Fenugreek
5	Maize + High value vegetablesMaize + FlowersBaby maize + VegetablesSweet maize + Vegetables	*Peri*-urban interface

Impact of crop with respect to uptake of nutrients and soil health

Nutrients plays pivotal role in maize cultivation. It requires 29.9 kg N, 13.5 kg P_2O_5 32.8 Kg K_2O for producing one ton of grain. This depends upon native soil fertility status and their supply through fertilizers and manures. The continuously indiscriminate and injudicious use of native soil nutrients and chemical fertilizers application not only lead to deteriorated soil health with reduced organic matter and multiple nutrient deficiencies but also leading to unsustainable productivity. Moreover, the use of the other chemicals like pesticides, insecticides also has negative impact on the quality of crop produce as well as soil health. As the consequence, it put a big question for sustaining the productivity of maize. Integrated nutrient management, which includes use of inorganic fertilizer with organic manures like crop residue, green manure, compost, bio-fertilizers *etc* holds a great promise not only in securing high levels of crop productivity but also against emergence of micronutrient deficiencies in soil and plant and also to protect soil health from deterioration and pollution hazards. Besides it, the efficiency of applied fertilizer also increased when applied along with organic manures. Several studies indicated that application of FYM, green manure, crop residues, bio-fertilizers and other wastes either alone or along with inorganic fertilizers enhanced the organic carbon and other plant nutrients in soil. Application of different organo-inorganic sources was found very effective in realizing high yield in maize and improved residual fertility of the soil.

5.9 Crop products

Value addition: Maize is a major cereal crop for human nutrition and is used in several ways. Maize is generally consumed in the form of chapatti, popcorn, roasted fresh cob *etc.* in India. A wide variety of products can be been developed which can meet nutritional need of vulnerable section.

Value added products based on normal/ QPM maize

- **Traditional products:** *Ladoo, halwa, kheer, chapati, sev, mathi, pakora and cheela*
- **Baked products**: Bread, *nan khatai*, biscuits and cake, chips
- **Extruded products:** Vermicelli and pasta;
- **Convenience foods**: Instant *idli* mix, instant *dhokla* mix and porridge mix, sprouted products-sprouted chat, QPM vada, QPM sevian, QPM flour
- **Infant food:** Infant food-I, Infant food-II, Infant food (flavoured), Infant food (enriched with vitamin A), Infant food (flavoured and enriched with vitamin A)
- **Health food-**QPM Mix-I, QPM Mix-II, QPM *ladoo,* honey maize chocolate, maize coconut chocolate, maize coconut toffee, maize groundnut toffee, choco maize bar, honey maize water
- **Snacks and savoury item**: QPM biscuit salted, QPM biscuit sweet, choco maize biscuit, honey maize chikki, maize matthi, namak para, sev, shakarpara, QPM burfi, QPM halwa, suji upama, suji kheer, sevian (sweet), sevian (upama), QPM chatni powder-I, QPM chatni powder-II, QPM chatni powder-III
- **Specialty foods :** High quality protein mix, low quality protein mix, quality protein mix for elderly, QPM honey liquid, honey maize water (Singh. 2006)

Value added products from blends of maize and legume: Maize was blended with soybean/ green gram in ratio 70:30 and the product developed includes:

- **Traditional products**: Cake, biscuit
- **Fried products :** *Halwa, upma, dalia, cheela, namakpara, sattu, khichri, burfi*
- **Dehydrated products** : Vadi and fryums

Value added products developed with baby Corn

- **Traditional products**: *Pakoda, cutlet, chat, salad*, dry vegetable, *kofta,* mixed vegetable, *raita*
- **Sweet products** : *Halwa, kheer, burfi*
- **Preserved Products :** Jam, chutney, pickle, candy, *murraba*
- **Chinese products :** Soup, manchurian, baby corn chili, chowmein, sweet and sour vegetable

Value added products of sweet Corn

- Sweet corn soup
- Thai basil and sweet corn

- Salted green beans with shallots and sweet corn
- Oganic speedchef- Pizza with garlicky greens and sweet corn
- Sweet corn cake
- High summer scallops with sweet corn and couscous
- Sweet corn and tomato salad

Value added products of popcorn

- Apple popcorn brittle
- Ballpark popcorn crunch
- Beach party popcorn
- Boston tea party popcorn
- Caramel corn crunch
- Caramel nut popcorn crunch
- Cherry almond popcorn clusters
- Chilli corn
- Red cinnamon popcorn
- Swiss onion popcorn
- Pina colada popcorn
- Patchwork popcorn party mix
- Kettle corn

Industrial Products of Corn: Corn is used in more than 3000 products in USA and more than 100 in India that include adhesives, antibiotics, automobiles, baby food, breakfast cereals, canned vegetables, cheese spreads, chocolate products, printings, cosmetics, crayon and chalk, dessert powders, dyes, edible oil, finished leather, k*etc*hup, livestock feed, malted products, paper manufacturing, pharmaceuticals, drugs and carpets, shoe polish , soft drinks, textiles, *etc*.

Snacks and savory products: Snacks and savory products are well suited to all age groups contributing balanced amount of nutrients. Socio-cultural change and changing life styles have created the demand for convenience food which is pre-packaged, pre-cooked and easy to handle. These foods should be cooked quickly and also ensures top quality, variety, taste and flavor.

Specialty foods: Majority of our population have been suffering from one or more problems due to deficiency/ metabolic disorders or certain accidents. In such cases, people require some nutrients in excessive doses and other nutrients in reduced amount for fast recovery. Patients having the problems of protein calorie malnutrition, *anaemia*, peptic ulcer, cirrhosis of liver, nephritis (type II), celiac disease *etc*. need high quality protein diet during recovery process. People having the problem of obesity, diabetes, gout, hyperthyroidism, arthritis, anorexia nervosa and allergies needs special protein by providing maximum quality protein per 100 kcal and by maintaining maximum balance between quality protein need and carbohydrates.

5.10 Major problems associated with storage of grains:

The basic problems generally associated with the storage of maize grains are:-

- Storage with high grain moisture (>13 %).
- Attack by insects, rodents and saprophytic fungi.
- Mechanical injuries
- Non availability of Grain drying system
- Non availability of proper storage containers

5.11 Researchable issues

- Development of diverse productive inbred lines resistant to biotic and abiotic stresses from temperate X tropical hybridization.
- Identification of nutrient-responsive, high water use efficient, high nitrogen use efficient, high sink efficient inbred lines and the underlying genes for combination breeding.
- Development of high yielding single cross hybrids for different maturity groups resistant/ tolerant to biotic and abiotic stresses.
- Development of high yielding single cross hybrids having temperate background suitable for winter season as well as assured irrigation in Indo-gangetic region of North Western plains.
- Development of germplasm with high biomass. Development of synthetic and composites with high biomass for fodder purpose. Maize x Teosinte hybridization programme for inducing tillering in maize.
- Identification of source germplasm for high Fe, Zn and Vit. A.
- Development of economically viable seed production technology based on specifics of region, cropping season, hybrid maturity, parental lines, etc.
- Synthesis of hybrid-oriented populations, Quality analysis and identification of tryptophan, lysine, carotene enriched material ; development of nutritionally superior inbreds and single cross hybrids
- Development of QPM germplasm with higher yield and identification of major and minor endosperm modifiers and their mobilization through genomic assisted breeding.

Package of practices for *kharif* maize

SOIL: Maize is best adapted to well drain sandy loan to silty loam soils. Water stagnation is extremely harmful to the crop, therefore, proper drainage is a must for the success of the crop especially during *kharif* season. Maize will not thrive on heavy clays, especially low lands. It can be grown successfully in soils whose pH ranges from 5.5 to 7.5. The alluvial soils of Uttar Pradesh, Bihar, Punjab and very suitable for growing maize crop.

FIELD PREPARATION: Maize kernels need a seedbed which is friable, well aerated, moist and weed free to provide better contact between the seed and the soil. There no need to prepare an extremely fine seedbed. The first ploughing should be done with soil inverting plough so that at least 20-25 cm deep soil may becomes loose. It should be following by two to three harrowings or three to four intercrossing ploughings with local plough. Planking should be done after each ploughing. While preparing the field for maize crop leveling must not be overlooked. A properly leveled and uniformly graded field is required for good water management.

TIME OF SOWING: Maize can be grown in all seasons *viz*; *kharif* (monsoon), post monsoon, *Rabi* (winter) and spring. During *Rabi* and spring seasons assured irrigation facilities required. During *kharif* season, in irrigated area it is desirable to complete the sowing operation 12-15 days before the onset of monsoon. However, in rain fed areas, the sowing time should be coincided with onset of monsoon. The optimum time of sowing are given below:

Season	Optimum time of sowing
Kharif	
North-western hills	April to early May
North-eastern hills	First fortnight of March
Peninsular region Indo-gangetic plains	May to June Last week of June to first fortnight of July
Rabi	Last week of October for inter cropping and up to 15th of November for sole crop.
Spring	First week of February.

Reference: Maize Production Technologies in India, DMR.

Seed Rate and Plant Geometry: To achieve higher productivity and resource-use efficiencies optimum plant stand is the key factor. The seed rate varies depending on purpose, seed size, plant type, season, sowing methods, *etc*. The following crop geometry and seed rate should be adopted.

Sl. No.	Purpose	Seed rate (kg/ha $^{-1}$)	Plant geometry (plant x row, cm)	Plant population
1	Grain (Normal and QPM)	18-20	60 x 20 75 x 20 75 x 25	83333 (I)* 66666 (I) 53333 (R)
2	Sweet corn	6-7	75 x 25 75 x 30	53333 44444
3	Baby corn	25-30	60 x 20 60 x 15	83333 111111
4	Pop corn	10-12	60 x 20	83333
5	Green cob	18-20	75 x 20 60 x 20	66666 83333
6	Fodder	75-80	30 x 10	333333

*R: rainfed; I: irrigated

Certified seed of improved varieties should be used for sowing. Before planting, the seed lot must be tested for its germination percentage and the seed quantity to be adjusted accordingly. For getting the highest yield it is necessary to use new hybrid seed every year. The yield may be reduced by using the seed from one's own hybrid crop, by about 30 percent. However, the composite maize varieties do not have this characteristic and therefore, a farmer can use the seeds from his own composite crop for next year also, provided no mixture has been allowed in the field and at the threshing floor. It is advisable to change the seed of composite also after every three years.

Seed should be treated with Bavistin of Derosal of Agrozim at the rate of 3g/kg of seed.

METHOD OF PLANTING: Plant maize across the slope at a seed 3-5 centimeter depth. The planting depth to a considerable extent will depend on the moisture status of the field and the type of soil. If the soil is dry and sandy, it would be advisable to plant deeper. Usually planting is done by one of the following methods:

(a) *Planting on the side of a ridge*: In saline soil affected areas.

(b) *Planting on the ridge*: This method is adopted in high rainfall situations and on lands not uniform.

(c) *Planting in narrow furrows*: This method is adopted in low rainfall areas.

(d) *Planting in a flat bed with no earthing up*: In normal conditions.

(e) *Planting on flat bed and earthing up-after 35-40 days of planting*: In areas where there are heavy storms during rainy season.

MANURES AND FERTILISERS: Manures and fertilizers both play important role in the maize cultivation. A liberal quantity of bulky manures should be applied in the field if available. Add 10 tons of well rotted organic matter in the form of farm yard manure or compost before sowing. The application of organic matter to the soil ensures good tilth and improves water holding capacity.

Hybrid and composite varieties of maize exhibit their full yield potential only when supplied with adequate quantities of nutrients of proper time. A crop of maize yielding about 14 tons of dry matter (both grains and stover) takes up about 161 kg N, 34 kg P and 110 kg per hectare. The exact quantity of the fertilizer that has to be applied to the soil will depend not only on the plant requirements of individual nutrients but also on how much of them the soil can supply. However, as a general recommendation, one could apply 150 kg N, 75 kg P_2O_5 and 50 kg K_2O per hectare for medium and late maturity hybrids and 100 kg N and 40 kg P_2O_5 and 25 kg K_2O per hectare for early maturity hybrids and composite.

TIME AND METHOD OF FERTILIZER APPLICATION: The time of fertiliser application is as much important as the quantity applied. As far as nitrogen is concerned; major part of the nitrogen uptake by the crop is over by the tasselling stage. In general, it would be advisable to apply the total quantity of P and K and 15 % of nitrogen at planting and split up the remaining N in three splits, 40% at knee high; 35 % at flowering and ; 10% at grain filling stages . In case of nitrogenous fertilizers care should be taken not to apply when the field is very wet after heavy showers because the nitrate formed is most likely to be lost out of the feeding zone of the plant by leaching.

The method of fertilizer application is also very important. The basal dose should be placed in the soil. This can be done with the help of fertilizer drill and if it is not possible use a funnel attachment behind the plough. The fertilizer should be placed about 3-5 centimeter to the side and 3-5 centimetre deeper than the seed. The remaining nitrogen is top dressed at the appropriate time between two plant rows.

In some parts of the country, where the soils are deficient in zinc, it is advisable to apply 20-25 kg zinc sulphate per hectare before planting.

Maize plants manifest the nutritional deficiency of nitrogen, phosphorus, potash and zinc which are briefly given below:-

Nitrogen: Plants are stunted in growth with pale yellow colour of foliage. In advanced stage of deficiency older leaves become yellow and this symptom proceed upwards from the base, yellowing starting from the tip of leaves and advancing towards the base in a ‘V’ shaped pattern.

Phosphorus: Phosphorus deficiency is often characterised by stunted growth, poor root development, purpling of leave at leaf tip and leaf margins and sometimes abnormally dark green leaf colour is observed.

Potas: Potassium deficiency results in a characteristic pattern of leaf discolouration by small whitish-yellow spots, followed by scorching or browning of yellow streaking of leaf edges.

Zinc: Zinc deficient plants are stunted in growth, pale green in colour. Chlorotic spots are seen at the base of the leaves near the margins. However, margins and midribs remain green. In severe cases the apical leaves become white, a symptom called ‘white bud’ of maize.

WATER MANAGEMENT: Maize is very sensitive both to excess water and moisture stress conditions. Water stagnation even for six hours continuously under high temperature condition damages the crop. If the crop is planted on the ridges and there is provision of surface drainage at the lower end of field, the harmful effects of water logging can be minimized. Maize is grown in rain fed regions, where the distribution of rainfall is enough to ensure adequate soil moisture during life cycle of the crop. A good crop of maize requires about 460 to 600 millimeter of water during its life cycle. Do not allow maize plants to wilt due to water shortage at any stage of the life cycle. Tasselling to silking stage is critical. At this stage water shortage even for 2 days can reduce maize yields by about 20 per cent. The same for 6-8 days can pull down the yield by 50 per cent. Irrigate the crop whenever it is needed. In general, when rainfall is scanty, 1 or 2 irrigations at the critical stages are required for stabilizing the yield. Winter and spring maize should be planted only under assured irrigation conditions. In these season irrigations as per requirement should be applied to maintain the proper moisture condition in the field and generally 7-9 irrigations are required to get the good crop.

WEED CONTROL: The abundant rainfall in *kharif* encourages rapid weed growth. Weeds emerge with the germination of maize seeds and grow along with plants till the early growth period. This causes severe crop weed competition. Failure of timely weed control would not only offer direct competition to the maize plant but also indirectly through reduction in fertilisers use efficiency. Losses through weed free later. In case the weeds are not brought under control at right time, there is 50-60 per cent reduction in yield. Maize crop is infested with grassy and broad-leaved annual weeds. Among grassy weeds, *Echinochloa crusgalli, Acrachne racemosa, Digitaria sanguinalis, Dactyloctenium aegyptium, Paspalum dialatum and Cynodon dactylon* are common. The broad-leaved weeds are *Trianthema portulacastrum, Trianthema monogyna, Digera arvensis, Commelina benghalensis, Phyllanthus niruri, Xanthium strumarium, Boerhaavia diffusa, Oxalis corniculata and Parthenium hysterophorus*). Sedges are *Cyperus rotundus, Cyperus esculentus and Cyperus iria.*

It is very difficult and economically not feasible to keep the crop weed free throughout the growing season. The maize crop kept weed free for 30 to 45 days after planting is almost similar in yield as that kept weed free for entire crop season. Two to three manual weedings would be needed for this purpose. Generally *khurpi*, hand hoe and spades are used for weed control in maize. At many places, people use cultivator or country plough in between the rows of maize. Sometimes due to continuous rains during the early period of maize growth, it becomes impossible to enter in the field. In such a situation the only effective way to control weeds is the use of pre-emergence herbicides. The following herbicides can be use in maize crop.

Atrazine: The herbicides may be applied immediately after planting maize. The rate of application varies from 1.0 to 1.25 kg of active ingredient in light soils and 1.25 to 1.50 kg of active ingredient in heavy soils per hectare. The weedicide should be mix in 600 litres of water and evenly sprayed on the soil surface just after sowing. There should be enough moisture in the soil at the time of spraying. Care should be taken that the seedbed is well prepared and does not contain any emerging weed. Field should not be disturbed for initial three to four weeks.

DISEASES: Maize crop suffers from different pathological maladies resulting in considerable loss in yield. Symptoms of important diseases and their suitable control measures are given below:-

Seed and Seedling Blights: Germinating maize seedlings are attacked by number of soil borne or seed borne fungi that causes seed rot & seedling blight consequently plant stand is reduced. Symptom appears as brown sunken lesions on mesocotyl, rotting at collar region leading to wilting & toppling of seedlings. The disease poses a serious problem in temperate areas by reducing plant stand. However, they are not a serious threat in the major tropical environments of India because of rapid emergence of seedlings. A variety of pathogens are associated with seed rots and seedling blights including species *Pythium, Fusarium, Acremonium, Penicillum, Rhizoctonia, Macrophomina, Sclerotium etc*.

Management

1. Eliminate lightweight, chaffy, injured or infected seeds by sieving/winnowing.
2. Use certified seeds.
3. Proper seed bed preparation, planting seed in warm, fairly moist soil (above 12.8°C).
4. Treat seed with Thiram/Captan @ 2 g/kg seed.

Turcicum Leaf Blight: Slightly oval water-soaked, small spots are produced on leaves which grow into long, elliptical, grayish green or tan lesions ranging from 2.5 to 15 cm. in length develop first on the lower leaves and later on the disease progresses upward on the plant. The disease can develop rapidly after anthesis resulting in complete blighting of leaves. In damp weather, large number of grayish black spores are produced on the lesions; lesions may form on the outer husks. Severe infection causes a premature death and gray appearance that resembles frost or drought injury.

Management

1. Practice rotation of maize with non-host crops to reduce disease incidence.
2. Sanitation, clean plough down of infected crop debris.
3. Spraying with mancozeb(Dithance M-45/Indofie M-45) or zineb (Dithance Z-78)@ 2 - 4g/litre at 8-10 days interval.

Maydis Leaf Blight : Lesions on the leaves caused by race '0' are elongated between the veins, tan, 2-6 x 3-22 mm long with limited parallel margins and buff to brown borders. Lesion size may vary in inbreds and hybrids due to different genetic backgrounds. Lesion produced by race 'T' is tan, 0.6-12 x 0.6-2.7 cm. elliptical with yellow green. Later, the race 'T' lesion have dark, reddish brown borders and may occur on the leaves, stalks, leaf sheath, ear husk, ear; and cob rot can also occur with substantial losses in harvesting and shelling. Seedling from infected kernels (Race 'T') may wilt and die within three to four weeks after planting. Severe blighting of leaves caused by either race predisposes plant to stalk rot.

Management : same as in case of turcicum leaf blight

Brown Stripe Downy Mildew : Initially, lesions develop on the leaves as narrow, chlorotic or yellowish stripes, 3-7 mm wide with well-defined margins and delimited by the veins. The stripes later become reddish to purple. Lateral development of lesions causes severe striping and blotching occurs prior to flowering. Downy or wooly cottony whitish growth occurs in early morning hours on lower surfaces of the lesions.

Management

1. Adopt other cultural practices like planting before rainy season, destruction of infected crop debris, weed control, reduced crop density, low seed moisture (<9%) at planting, low soil temperature (<20^0 C).
2. Seed treatment with metalaxyl (Ridomil 25 WP, Apron 35 SD) @ 2.5g/kg seed.
3. Foliar spray of systemic fungicide such as metalaxyl (Apron 35FN) @ 2-2.5g/Litre is recommended at first appearance of diseases.

Rajasthan downy mildew: Infected plants are chlorotic and the chlorotic area includes the base of the blade with transverse margin and easily defined between diseased and healthy tissue. Leaves of infected plants tend to be narrower and more erect than these healthy plants. A white downy growth may appear on lower surfaces of infected leaves. In severe cases the tassels of diseased plants may exhibit phyllody. There is no seed set in such plants. In tolerant varieties, the plant show symptoms of infection but have normal seed setting.

Management: same as in case of brown strip downy mildew

Banded Leaf and Sheath Blight: The disease appears on leaves and sheaths on 40-50 days old plants and later on spread to the ears. The characteristic lesions are first seen on lower leaves and sheaths (first and second) in the form of concentric bands and rings. The affected plant produces large, gray, tan or brown discoloured areas alternating with dark brown bands. Sclerotia later on appear in these diseased areas. The developing ear is completely damaged and dried up prematurely with cracking of the husk leaves. Brown rotting of the ears may develop which show conspicuous light brown cottony mold with small, round black sclerotia.

Management

1. Stripping of lower 2-3 leaves along with their sheath considerably lowers incidence and also does not affect grain yield.
2. Seed treatment with peat based formulation @ 16 g/kg of *Pseudomonas fluorescence* or as soil application @ 7 g/litre of water, carbendazim, thiophanate-methyl and captan.
3. Foliar spray (30-40 days old crop) of tolcofos-methyl (Rhizolex 50 WP) @ 10 g/10 litre or of validamycin@2.7ml/litre of water

Pythium Stalk Rot: Pythium stalk rot may occur prior to flowering. The rot is usually confined to a single internode just above the soil line. The diseased area of the stalk is brown, water-soaked, soft and the stalk is collapsed. The affected plants topple but do not die upto two weeks after attack. The plant gets twisted due to rotting at infected portion resulting in lodging, though, they do not break off completely. Infected plants remain green and turgid up to several weeks because the vascular bundles remain intact.

Management

1. Maintain plant population not more than 50,000/ha for good aeration in the field.
2. Ensure good field drainage to avoid waterlogging that helps in zoospore dispersal.
3. Destroy previous crop debris/wheat straw so that disease should not overwinter.
4. Application of 75% captan @ 12 g/100 litre of water as soil drench at the base of the plants when crop is 5 to 7 week old.
5. Solarization, fumigation and soil drenches with bioagents and fungicides to mitigate the soil inoculum.

Bacterial stalk rot: Bacterial stalk rot can infect the plant at any node from the soil surface up to the whole plant. Primary symptoms of discoloration (due to tan to dark brown, water soaked slimy lesions on the leaf sheath and stalk) generally appear when plant suddenly falls over and are seen scattered in the field. Splitting of stalk exposes internal discoloration and soft slimy rot at the nodes. Disease builds up in the stalk and rapidly spreads up the stalk and into the leaves leading to collapse of the plant affecting normal tasseling and pollination. In advance stage of infection, a foul odor can be sensed from macerated tissues and the top of such plants can be very easily removed from the rest of the plant. Affected plants may remain green for several days.

Management

1. Ensure proper drainage to avoid waterlogging.
2. Planting of the crop on ridges rather than flat soil.
3. Avoid use of sewage water for irrigation.
4. Bleaching powder containing 33% chlorine @ 10 kg/ha as soil drench at pre-flowering stage.

Charcoal Rot: This disease is prevalent in comparatively drier maize growing areas. This disease also becomes apparent as the plant approach maturity. Affected plants dry prematurely, the affected internodes become disintegrated and show black discoloration. Presence of numerous, minute black sclerotia on the vascular bundles and inside the rind of the stalks is a distinguishing character. The disease is usually confined to first or second internode above soil level. Water stress at or after flowering has been found to predispose the plant to infection.

Management

1. Deep ploughing, sanitation and removal of previous crop debris from soil.
2. Avoiding water stress at flowering time reduces disease incidence
3. Apply potash @ 80 kg/ha in endemic areas.
4. Grow plant varieties with good stalk strength.
5. Use *Trichoderma* formulation after mixing with FYM @ 10 g/kg and incubate for 10 days covered with wet gunny begs. This mixture should be used in furrows before sowing.
6. Seed treatment with fungicides. Ensure crop is not under nutrient stress.

Late Wilt: The first symptoms observed as moderately rapid wilting of the leaves beginning at tasseling time. The leaves turn dull green and then dry. Vascular bundles in the stalk are discoloured. Later, lower portion of the stalk become dry, shrunken and hollow with or without wrinkling turn purple to dark brown which is more prominent on lower 1-3 internodes. Some secondary organisms also develop on stalk rots that cause wet rot with some typical sweetish smell.

Management

1. Avoidance of moisture stress and balanced potash application reduce the incidence of the disease.
2. Seed from infected areas should not be planted.
3. Rotation with other crops.
4. Use resistant varieties and hybrids.

INSECT PESTS

Maize crop is subjected to attack by a number of insect pests. Some of the major insect pests are as follows:-

Spotted Stem borer: Leaf eaten by young larva when unfurled, displays pin holes in horizontal row, the more developed larvae feed downward the holes made are large and oblong vertically. As the larvae move downward feeding a 10-20 day old plant it reaches meristem which is also fed. The central leaf of such plant dries up making dead heart and the plant usually dies or give rise to tillers. Then they bore down inside the plant whorl or else move down the outside of the stem and bore into it just above an internode. While feeding in the plant whorl, they kill the central shoot which later on dries up causing dead heart formation. Early warning signs by young plants have pinholes in straight lines across the newest leaves. This is the time to treat before the caterpillars move into the stem.

Management

1. Collection and destruction of the stubbles which are left in the field or heaped in one corner of the field since they act as a source of infestation as the larvae hibernate in them.
2. Removal of the dead hearts
3. Release of *Trichogramma chilonis* 8 cards/ha at 12 and 22 days after germination. Alternatively spray carbaryl@ 2.5g/l water.
4. Intercropping of maize with suitable varieties of cowpea is an eco-friendly option for reducing the incidence
5. Need based application of carbofuran 3G into whorls of infested plant @a pinch of granule per plant.

Pink stem borer: The larvae bore into the central shoot resulting in drying up of growing point and formation of dead heart in young plants. The larvae form circular‘s’ shaped tunnels inside the stem and exit holes at the surface filled with excreta.

Management

1. Deep summer ploughing
2. Use of trap crops like cowpea, jowar in 3-4 rows
3. Release of *Trichogramma chilonis* @ 8 cards/ ha at 12 and 22 days after germination on weekly interval
4. Need based application of a pinch of granule of carbofuran 3G in whorl of infested plant is recommended. It cannot be applied late in the season because of residues in the grain.

Shoot fly: Damage occurs from one week to four weeks after seedling emergence resulting in wilting and drying of the central leaf, known as a dead heart which can be pulled out easily and produces bad smell. The damaged plants produce side tillers which may also be attacked.

Management

1. A higher seed rate is adopted and the affected seedlings are pulled out and destroyed.
2. Sowing must be completed before first week of February so that the crop will escape shootfly infestation
3. Removal and destruction of affected shoots along with the larvae
4. Seed treatment with imidacloprid @ 6 ml/kg seed reduces the incidence significantly

Cob borer: Larvae feed on silk and tassel. These larvae may tunnel into the ears. When fresh silk is available the eggs are laid on the silk, and the larvae first feed on the leaves or bore directly into the silk and the kernels at the tip of the ear are eaten down to the cob. They destroy the grain mostly inside the panicle and filled with frass. The damage reduce the market price of green cob, though not much loss to the grain occurs.

Management

1. Hand picking and destruction of larvae
2. Installation of pheromone traps @10/ ha for monitoring purpose
3. Release of *Trichogramma chilonis* @ 8 cards/ ha
4. Natural enemies present in maize ecosystem are *Trichogramma*, Braconids, Tachinids and NPV

Termites: Termite invasion initiates from dry leaves. Later, roots as well as the lower part of the stem are destroyed resulting in lodging. Vascular tissues might be damaged and wilting would occur espe-cially under water stress con-ditions. In extreme cases, the ears are invaded by term-ites. Severely damaged plants may lodge and completely destroyed by termites.

Management

1. Clean cultivation delays termite attack.
2. Care should be taken to avoid partially decomposed manure.
3. If the termite incidence is in patches, spot application of spray of Chlorpyriphos @ 3-5ml/l of water is recommended.
4. Irrigation of field also reduce termite for a short period.

Aphid: Aphid sucks the sap from the whorl leaves during the vegetative stage of the crop. It also feeds on the panicles, and produces honeydew on which sooty moulds grow. However, its infestations rarely reach damaging proportions. If young plants infected they seldom produce ears. The aphid colony may sometimes cover completely the emerging tassels and the surrounding leaves preventing the emergence. Ears and shoots are also infested and seed set may be affected. The tassel, if heavily damaged might be-come sterile.

Management: Maize ecosystem is endowed with good number of natural enemies of aphids, prominent among them are coccinellids, syrphids and chrysopids. Because of copious production of pollens, these predatory insects thrive well and often contain the aphid population and do not allow the aphids to cause much economic loss.

Tobacco caterpillar and Lucerne caterpillar

Nature of damage:

On hatching larvae feed on the tender leaves in groups. They scrape the surface but do not actually perforate it, creating a window pane effect. Under severe infestation, the entire young plant may be consumed. Later on migrate and feed on the leaves which gives thin papery appearance. The pest activity is observed in *rabi* season

Army worm: Plants are damaged by all the stages of caterpillars. Larvae feed on tender leaves and skeletonize them. In case of severe attack leaves including midribs are eaten away and the fields look as if grazed by cattle. Larvae excrete faecal matter in the form of pellets which are seen in the plant whorls. Larvae also damage immature ears.

Management

1. Hand picking and destruction of larvae
2. Need based spray of chloropyriphos 20 EC or quinalphos 25EC @ 1L/ha should be given

Flower eating beetle: The pest is serious on maize at the time of flowering. The adult beetles feed on the pollen silk and results in poor seed set.

Management

1. Deep ploughing of infested field to kill the grubs in the soil.

2. Hand picking of adults.

HARVESTING AND THRESHING: Harvest maize crop when husk has turned yellow and grains are hard enough having less than 30 per cent moisture. Do not wait for stalks and leaves to dry because they remain green in most of the hybrid and composites.

Remove the husk from the cobs and then dry them is sun for seven to eight days. Thereafter, grains are removed either by beating the cobs by sticks or with the help of maize shellers.

YIELD: By following improved cultivation practices as indicated above, it gives 50-60 quintals of grain per hectare in cases of hybrids and 45-50 quintals in case of composites under irrigated conditions. In case of rain fed crop yield levels are about 20-25 quintals for hybrids and 15-20 quintals for composites.

Package of practices of rabi maize

Investigations have shown that *Rabi* maize favourably responds to better crop management, which can be effectively practiced, and the *Rabi* yield levels realized in India can be compared with those currently obtained in the USA, Europe and other developed countries.

Reasons for high yields in *Rabi are given as under:-*

1. Better Water Management : In absence of erratic rainfall, the crop during *Rabi* does not suffer from water logging, leaching of fertilizers and damage from pre flowering stalk-rots. Probably the most important advantage rests in the possibility of undertaking various field operations at the most desired time. The *Rabi* crop does not suffer from overcast sky. During *Rabi*, 7-9 or more hours of sunshine is received, against 3-5 hours during *Kharif* crop season.

2. Mild and Favourable Temperature : Maize plants in *Rabi* tend to be more efficient in view of lower photo respiration losses due to lower night temperature as well as larger effective photosynthetic leaf surface. Moreover, the longer growing duration of the crop helps further in raising the yield levels.

3. Better Response to Macronutrients: In view of more favourable growing conditions, the response to the application of nitrogen and other nutrients is better in *Rabi* than *Kharif*. The losses during *Rabi* can be checked effectively through appropriate soil and water management practices. With better response from every unit of fertilizers, which is the major component of the cultivation cost, it is possible to reduce the production cost during this session.

4. Management of Diseases and Insect-pests: The level of infection of infestation and the extent of damage due to various diseases and insect pests in *Rabi* is lower than in *Kharif*. This is mainly due to the low temperature and humidity.

5. Establishment of Better Plants Stands : Because of better soil and water management and less damage from diseases and pests, establishment of desired plant population density (essential for realizing optimum yield) can more conveniently be ensured in *Rabi*.

6. Better Weed Management : In *Kharif* weeds pose a major threat, particularly in years when continuous rain occurs, which fail to provide adequate opportunity for manual weeding. But during *Rabi*, due to effective water management and low temperature, weeds can be control effectively. This indirectly also helps in improving the fertilizer-use efficiency.

Choice of Variety:

The success and margin profit from *rabi* crop depended to a great extent on the choice of maize hybrid to be grown. The open pollinated varieties traditionally grown in *kharif* are not likely to give high yield in *rabi*. Farmers should therefore be encouraged to sow only late maturity single cross high yielding hybrids suitable for *rabi* season.

Sowing Time

The optimum date of sowing is more important in *Rabi* than in *Kharif*. The temperature during the second fortnight of October to mid November in most of the north Indian plains drops rather sharply. This result in delayed germination and poor plant stand and growth receives a major setback.

Hence, any marked delay in sowing is likely to result in yield reduction. Also in late sown crops, there is an increased incidence of common rust, which is not a serious concern in timely sown crop. Generally, during *rabi* season sowing should be completed by the end of October with intercropping and up to 15 November under sole crop. In Punjab and Haryana, where the temperature at the time of sowing is low. It will be desirable to sow the crop on ridges. Sowing should be done on the southern side of the East-West ridge so that the optimum amount of sunshine can be received and the seedbed remains warm.

Fertilizer Application

The efficiency of nitrogen utilization is better in *Rabi* than in *Kharif* primarily because of better water management and lower leaching losses with better fertilizer response.

The available quantity of farmyard manure should be applied before sowing, since a combination of organic manure and inorganic fertilizers give better results than the use of fertilizer alone.

The quantity of fertilizer to be applied depends mainly on soil fertility and the preceding field management. In general, a balanced application of 180:80:60 Kg/ha of NPK is recommended.

In general, it would be advisable to apply the total quantity of P and K and 15 % of nitrogen at planting and split up the remaining N in three splits, 40% at knee high; 35 % at flowering and ; 10% at grain filling stages Nitrogen in form of urea should be carefully applied 15-20 centimetres away from the plants to avoid any leaf injury.

Best response from nitrogen is obtained when the top-dressed fertilizer is covered with light soil after application.

Seed Rate and Spacing

A population of 83,333-90,000 plants/ha at harvest is desirable for realizing high grain yield in *rabi*. A spacing of 60 cm between rows and 20 cm between plants would provide the desired plant population density. For this purpose 20-22 kg of seed would be needed to sow one hectare of land. Before sowing, seeds should be soaked overnight in warm water (45°C at the time of seed soaking). This treatment helps in obtaining better plant stand and healthy crop. Seeds should be sown 4-5 cm deep.

Weed Control

Broad-leaved weeds and most of the grasses can be conveniently controlled with the application of Atrazine @ 1 Kg/ha before seeding emergence. In addition 1 or 2 inter-cultivations are adequate to keep the weeds under control.

Irrigation

The rainfall during *Rabi* is rather inadequate for successful cultivation of high yielding maize hybrids. In fact timely availability of assured irrigation is one of the major factors determining the success of crop. Where soils are generally light, it is desirable to schedule the irrigations at 70% soil-moisture availability throughout the period of crop growth and development. In heavy soils, a moisture level of 30% during the vegetative stage and 70% during the reproductive and grain-filling period is desirable for obtaining optimum yield.

Four to six irrigations are needed during the *Rabi* crop season. If six irrigations are given, they should be applied at the following crop growth stages: two irrigation up to flowering at an interval of 20-25 days, one (essential) at the time of flowering, two after flowering, and one at the early grain-filling stage. If only five irrigations are given, irrigation at the vegetative stage may be avoided; and if only four irrigations are given, irrigation after the dough stage may be avoided. The irrigation schedule may, however, be changed suitably if adequate rains are received.

YIELD

By adopting package of practices as indicated above; it is possible to obtain 70-80 quintals of grain in case of hybrids and 50-55 quintals of grains in case of composites.

Value added products of Maize

Khajoor

Laddoo

Dahi Vada

Chatpati

Biscuit

Pop Corn

Corn flakes

Barley

6. Barley (*Hordeum vulgare* L.)

6.1 Introduction

Barley is one of the first domesticated cereals, most likely originating in the Fertile Crescent area of the Near East. Many references to barley and beer are found in early. Egyptian and Sumerian writing that are more than 5000 year old. Archaeological evidence of barley cultivation dates back to 8000 BC in Iran. There is now considerable evidence that the initial cultivation of barley in China and India occurred at a later date. Cultivated barley is one of 31 *Hordeum* species belonging to the tribe Triticeae, of family Poaceae. It is an annual diploid species with 2n=14 chromosomes. The genetic system is relatively simple, while the species is genetically diverse, making it an ideal study organism. Molecular evidence has revealed considerable homology between barley, wheat, and rye. Among the wild *Hordeum*, there are diploid, tetraploid, and hexaploid species and many are perennial.

It is mainly used as cattle feed directly or as a component in feed concentrate. In hills, barley is the main staple food crop in the tribal area and also utilized in preparation of the local beverages. In the modern time it is more preferred as medicinal food in urinary problems.

The malt is consumed for brewing, distillation, baby foods, cocoa-malt drinks and medicinal syrups purposes. About 20-25% of the total barley production is used by industry but even this quantity is not available with desired quality. The barley requirement for malting is expected to rise further as indicated by the increase in consumption of more beer, energy drinks and confectionary items in urban society and their spread in rural areas.

In India, barley is an important coarse cereal crop, being grown in rabi (winter) season in northern plains and also considered as poor man's crop because of its low input requirement and better adaptability to harsh environments and better adaptability for fragile ecology, like drought, salinity-alkalinity and marginal lands and these factors are responsible for its lower productivity.

Morphology: The barley plant very much resembles the wheat plant and usually grows 0.75 to 1 metre in height. The botanical description of main parts of barley plant is given below:-

Root System: In consists of shallow and deep roots. The shallow roots arise near the soil surface and spread out laterally about 15-30 cantimetre almost at right angels to the tillers. The deep roots extend downwards into deep layers of soil. The depth of penetration various from 0.75 to 150 cm.

Stem (Culm): The stem is cylindrical and possesses five to seven hollow internodes separated by solid nodes, at which the leaves arise. The internode are short at the base of the plant and the length increases from the base of the culm upwards. The nodes may be either exposes or hidden by the sheath depending on the kind of barley variety. The usual number of tillers per plant varies from two to five.

Leaves: Leaves arise from nodes of the stem and are borne alternately on opposite sides of the stem. Each leaf consists of a sheath, blade, ligule and auricle. The leaves of barley are usually broader and of lighter green colour than wheat. The leaf sheath is generally glabrous, but in a few varieties it is covered with hairs. The leaf blade is lanceolate linear. The possess small ligule (0.5 to 3 millimetre). Auricles are very conspicuous, which partly or entirely clasp the stem and are much large than those in wheat. The surface of leaf is rough. Two-rowed barleys have narrower leaves than six-rowed barleys.

Inflorescence: The inflorescence is called spike or head. The spike at the top of the stem consists of spikelets attached at the nodes of a zigzag rachis. Each spikelet has two glumes and a floret. Three spikelets are attached at each node of the rachis. In two-rowed barleys only the central spikelet is fertile, whereas in six-rowed barleys all the three spikelets are fertile. The rachis is tough in all cultivated varieties of barley. Each barley spikelet has two glumes which terminate in an awn that may be shorter or several times longer than the glume itself. The length of glume awn is a very useful character of distinguishing varieties. The barley flower has three stamens, and a pistil with a single ovule and s stigma. The lodicules are present at the base of pistal and serve to open the flower by swelling during pollination. Barley is a normally self pollinated crop.

Kernel (Grain): The grain of barley is a caryopsis consisting of lemma, palea and a rechilla. In most of the barley varieties the lemma and palea adhere to the caryopsis. Whereas in others (naked barley) they are free and the caryopsis threshes out like wheat. The caryopsis is composed of the pericarp, endosperm and embryo.

Area under the crop is concentrated in the states of Rajasthan, U.P., M.P., Punjab, Haryana, and Bihar in plains and Himachal Pradesh, Uttarakhand and Jammu & Kashmir in the hills. Barley occupies 0.66 million ha area producing 1.50 million tons grain, with a per hectare productivity of 2292 kg. Presently the productivity is below the world average, but there has been a continuous gain in productivity through research efforts on varietal development and production technology. In India also, the trend of reduction in area under barley has been similar to world trend over the years. However, during past 15-20 years the area under barley has almost stabilized with minor annual fluctuations depending upon the market prices and industrial demand. State-wise normal Area, Production and Yield of barley is given at **Table-50**.

Table-50: State-wise Normal Area, Production and Yield of barley (Average of 2007-08 to 2011-12)

States	Season	Area ('000' ha)	Production ('000' tonnes)	Yield (Kg/ha)
Bihar	*Rabi*	14.3	17.7	1237
Haryana	*Rabi*	42.8	144.8	3383
Himachal Pradesh	*Rabi*	22.3	25.7	1150
Jammu & Kashmir	*Rabi*	12.5	7.4	589
Jharkhand	*Rabi*	5.8	5.5	942
Madhya Pradesh	*Rabi*	74.7	101.8	1363
Punjab	*Rabi*	14.0	50.0	3571
Rajasthan	*Rabi*	273.1	756.2	2769
Uttar Pradesh	*Rabi*	163.7	360.7	2204
Uttarakhand	*Rabi*	24.6	26.4	1074
Others	*Rabi*	8.3	8.1	974
All India	**-**	656.2	1504.3	2292

6.2 Comparative analysis

The state and season specific distribution of grain barley in the country is given in **Table-51.**

Table-51: State/season specific distribution of barley in India (2007-08 to 2011-12)

State	Area ('000' ha)		Production ('000' tonnes		Yield (Kg/ha)
	Area	% share to All India	Production	% share to All India	
Rajasthan	273.1	41.6	756.2	50.3	2769
Uttar Pradesh	163.7	24.9	360.7	24.0	2204
Madhya Pradesh	74.7	11.4	101.8	6.8	1363
Haryana	42.8	6.5	144.8	9.6	3383
Uttarakhand	24.6	3.7	26.4	1.8	1074
Himachal Pradesh	22.3	3.4	25.7	1.7	1150
Bihar	14.3	2.2	17.7	1.2	1237
Punjab	14.0	2.1	50.0	3.3	3571
Jammu & Kashmir	12.5	1.9	7.4	0.5	589
Jharkhand	5.8	0.9	5.5	0.4	942
Others	8.3	1.2	8.1	0.5	974
All India	656.2	100	1504.3	100	2292

Rajasthan State has largest area (41.6%) in the country followed by Uttar Pradesh (24.9), Madhya Pradesh (11.4%) and Haryana (6.5%). Rajasthan has also highest production (50.3%) of the country followed by Uttar Pradesh (24%), Haryana (9.6%) and Madhya Pradesh (6.8%). However, Punjab State has recoreded highest productivity (3571 Kg/ha) followed by Haryana (3383 Kg/ha) and Rajasthan (2769 Kg/ha). The average productivity of barley in the country is 2292 Kg/ha.

Barley ranks fourth among the cereals after rice, maize and wheat in worldwide production. It is a major source of food for large number of people living in the cooler semi-arid areas of the world. It is an important crop for direct human consumption and for animal feed. Barley is unique as a source of malt for beer and other products around the world. More than 52 m ha area is cultivated annually in the world under barley and more than 139 m tones of production with an average productivity of 2670 Kg/ha (**Table-52**). Russian Federation ranks 1st in production followed by France, Germany, Ukraine, Canada, Spain, Australia and Turkey. India ranks 21st area and 23rd in production with a lower productivity as compared to World average productivity due to poor and marginal land with less inputs.

Table-52: Mean area, production and yield of barley (2007-2011)

Sl.No.	Country	Area (Lakh ha.)	Production (Lakh tonnes)	Yield (Kg/ha)
1	Russian Federation	76.3 (14.6)	163.8 (11.7)	2147
2	Australia	44.3 (8.5)	76.7 (5.5)	1733
3	Ukraine	42.5 (8.1)	96.0 (6.9)	2259
4	Spain	30.6 (5.9)	94.0 (6.7)	3069
5	Turkey	30.6(5.9)	70.8 (5.1)	2313
6	Canada	30.3 (5.8)	95.3 (6.8)	3141
7	Morocco	20.6 (3.9)	21.5 (1.5)	1045
8	Germany	18.0 (3.5)	107.6 (7.7)	5971
9	France	17.0 (3.3)	106.8 (7.7)	6276
10	Kazakhstan	16.8 (3.2)	21.8 (1.6)	1302
11	Iran (Islamic Republic of)	14.9 (2.9)	29.4 (2.1)	1964
12	Syrian Arab Republic	13.8 (2.6)	6.5 (0.5)	469
13	United States of America	12.2 (2.3)	44.1 (3.2)	3612
14	Poland	11.5 (2.2)	36.9 (2.6)	3222
15	Ethiopia	10.3 (2.0)	15.2 (1.1)	1473
16	United Kingdom	9.9 (1.9)	57.3 (4.1)	5769
17	Algeria	9.1 (1.7)	12.4 (0.9)	1369
18	Iraq	7.3 (1.4)	7.2 (0.5)	992
19	China, mainland	6.7 (1.3)	24.2 (1.7)	3603
20	Argentina	6.7 (1.3)	23.1 (1.7)	3445
21	India	6.6 (1.3)	14.5 (1.0)	2204
22	Belarus	6.5 (1.2)	20.4 (1.5)	3148
23	Denmark	6.2 (1.2)	32.3 (2.3)	5176
24	Finland	5.1 (1.0)	18.3 (1.3)	3614
25	Czech Republic	4.4(0.8)	19.1 (1.4)	4341
26	Romania	4.3 (0.8)	11.1 (0.8)	2564
27	Tunisia	4.0 (0.8)	5.1 (0.4)	1290
28	Sweden	3.4 (0.7)	14.8 (1.1)	4333
29	Italy	3.0 (0.6)	10.9 (0.8)	3575

Sl.No.	Country	Area (Lakh ha.)	Production (Lakh tonnes)	Yield (Kg/ha)
30	Hungary	3.0 (0.6)	11.0 (0.8)	3620
31	Lithuania	3.0 (0.6)	8.3 (0.6)	2813
32	Mexico	2.6 (0.5)	6.2 (0.4)	2354
33	Azerbaijan	2.5 (0.5)	5.7 (0.4)	2298
	World total	**522.2 (100)**	**1394.4 (100)**	**2670**

NB: Figures in parenthesis indicate % share to World total.

6.3 Varietal improvement

The highest increase in barley yield was recorded in Central Zone (37.69 %) followed by Northern Hills Zone (35.22 %), North Eastern Plains Zone (32.68 %) and North Western Plains Zone (8.46 %). Therefore, efforts should be made to increase barley yield in the North Eastern Plains Zone and Central Zone in collaboration with the State Department of Agriculture.

Zone wise yield gain under FLDs

Zone	FLDs Yield (q/ha)	Regional Mean Yield (q/ha)	% Increase
NHZ	24.34	18.00	35.22***
NEPZ	29.56	22.28	32.68***
NWPZ	44.25	40.80	08.46***
CZ	39.93	29.00	37.69***

*** Significant at 1 per cent level

State wise yield gain under FLDs

State	FLDs Yield (q/ha)	Check Yield (q/ha)	% increase
HP	24.34	18.07	34.70***
UP	29.56	24.04	22.96***
Punjab	41.15	36.44	12.93**
Haryana	47.63	43.49	09.52***
Rajasthan	40.40	38.00	06.32**
MP	39.45	29.78	32.47***

*** Significant at 1 percent level, ** - Significant at 5 percent level.

The highest increase in barley yield was recorded in Himachal Pradesh (34.70 %) followed by MP (32.47 %), UP (22.96 %), Punjab (12.93 %) and Haryana (09.52%) . The lowest increase in yield was reported in Rajasthan (06.32 %).

Centre wise performance of improved barley varieties

Zone	Centre	BFLDs Yield (q/ha)	Check Yield (q/ha)	% increase
NHZ	Bajaura	25.09	17.34	44.69***
	Shimla	22.33	20.00	11.65**
NEPZ	Faizabad	29.00	21.73	33.46***
	Mirzapur	30.00	25.90	15.83*
NWPZ	Ludhiana	37.85	31.45	20.35 NS
	DWR Karnal (UBL Patiala)	43.50	40.00	08.75**
CZ	Hisar	47.63	43.49	09.52***
	Udaipur	40.40	38.00	06.32**
	Rewa	39.45	29.78	32.47***

*** Significant at 1 percent level, ** - Significant at 5 percent level, * Significant at 10 percent level, NS– Non-significant

The yield gain at Bajaura (44.69 %) centre was highest followed by Faizabad (33.46 %), Ludhiana (20.35 %) and Mirzapur (15.83 %) centers across the zones. The increase in improved variety's yield at Udaipur over check variety was the lowest (06.32 %).

Variety wise performance of improved barley varieties

Zone and Centre	Improved Variety	Average Yield (q/ha)	Check Varieties	Average Yield (q/ha)	% increase Over Check
NHZ					
Bajaura	BHS 380	26.39	Local	15.29	72.60**
	HBL 391	23.79	Local, HBL113	19.40	22.63 NS
Shimla	BHS 380	22.33	Local	20.00	11.65**
NEPZ					
Faizabad	NDB 1173	27.67	Local	21.67	27.69 NS
	JB 58	33.20	Jagriti	25.30	31.23*
Mirzapur	NDB 1173	29.80	Local	21.76	36.95***

Zone and Centre	Improved Variety	Average Yield (q/ha)	Check Varieties	Average Yield (q/ha)	% increase Over Check
NWPZ					
Ludhiana	DWRUB 52	37.85	VJM 201	31.45	20.35 NS
DWR Karnal (UBL Patiala)	DWRUB 64	43.50	PL 426	40.00	08.75**
Hisar	BH 885	48.90	BH 393	43.03	13.64 NS
	BH 902	47.43	BH 393	43.56	08.88***
CZ					
Udaipur	RD 2715	40.40	Local	38.00	06.32**
Rewa	JB 1	40.68	Local	29.94	35.87***
	JB 58	34.55	Local	29.15	18.52 NS
Dual Purpose Barley					
CZ – Udaipur					
Av. Grain yield (q/ha)	RD 2715	40.40	Local	38.00	06.32**
Av. Green Fodder yield (q/ha)	RD 2715	198.00	-	-	-

*** Significant at 1 percent level, ** - Significant at 5 percent level, * Significant at 10 percent level, NS– Non-significant

The yield gain (72.60%) of improved variety over the check variety was more at Bajaura center because the improved barley variety was compared with the local variety. In NHZ, BHS 380 was the highest average yielding (26.39 q/ha) variety at Bajaura centre. In NEPZ, JB 58 at Faizabad (33.20 q/ha), BH 885 at Hisar (48.90 q/ha) in NWPZ and JB 1 at Rewa (40.68 q/ha) in Central Zone were the highest average yielding varieties.

Yield Potential of barley varieties in different zones

Zone	Centre	Variety	Yield(q/ha)
NHZ	Bajaura	BHS 380	32.20
NEPZ	Mirzapur	JB 58	42.50
NWPZ	Hisar	BH 902	55.50
CZ	Udaipur	RD 2715	45.00

At particular farmers' field as well as on average basis BHS 380 (32.20 q/ha), JB 58 (42.50 q/ha), BH 902 (55.50 q/ha) and RD 2715 (45.00 q/ha) performed better than other varieties at Bajaura, Mirzapur, Hisar and Udaipur centres in the NHZ, NEPZ, NWPZ and CZ, respectively

6.4 Climatic requirement

Barley requires cools weather during early growth and warm and dry weather at maturity. It grows fairly well in temperature as well as in subtropical regions of the earth. This crop has low water requirement than wheat. Being drought resistant, barley suits areas with scanty rainfall. In India it is grown in the plains and in the higher regions of the Himalayas, up to 4000 metres altitudes. It is grown mostly in those regions where cultivation of wheat does not give economic yield.

6.4.1 Growth stages and climatic limitations in the development of barley

Barley has six well defined growth stages as detailed below.

Germination and seedling stage: This stage starts from seeding to 20-25 days after sowing (DAS). With germination, the coleoptile emerges out of soil producing leaves. This stage ends with the exhaustion of endosperm and crown root initiation.

Tillering: This phase lasts up to 30-35 DAS during which, tillers emerge from the crown and grow along with the main stem. Tillering is more in 2 rows than 6 row barley.

Jointing: This is also called shooting stage and lasts up to 55-65 DAS. The stem becomes visible, nodes multiply and inter nodal distance becomes longer. Flag leaf (the last leaf covering ear), emerges. The lower leaves starts withering while younger leaves continue to emerge and grow.

Heading (earing stage): The ear emerges from flag leaf and anthesis of central floret begins. This stage lasts up to 75-85 DAS and ends with production of watery grains.

Ripening: This stage lasts up to 90-100 DAS and involves post milking, grain filling and development. The grains gradually become hard.

Maturity: The grains loose moisture and plant parts get dried in the phase.

Barley performs best when flowering and grain filling take place while temperatures are moderate and soil moisture is adequate. A mean daily temperature of 12-15°C and 30°C during growth and ripening phases respectively are best for barley cultivation.

Growth stages and climatic limitations in the development of barley

Development stage	Temperature (°C)		
	Minimum	Optimum	Maximum
Sowing and germination	2-4	20-25	27
Tillering, initiation of ear primordia	-	< 8	-
Beginning of stem elongation and formation of ear primordia	-	< 9	-
Flag leaf, floret reduction, booting	-	< 14	-
Flowering and grain initiation	-	< 17	-
Grain formation	-	< 19	-
Maturing of the grain	-	19	-

Source: Aigner et al., 1988; modified

6.4.2 Impact of rise in temperature on yield of the barley crop

In temperate cereals, optimum mean temperature ranges for maximum grain yields were between 14 and 18 °C (Chowdhury & Wardlaw, 1978). On the other hand, as maturation processes of cereals are related to specific temperature sums, moderate increases in average temperatures by 1–2°C result in shorter grain filling periods and negatively affect yield components in some regions (Barnabas et al., 2008 and Savin et al., 1997). Earlier studies thus demonstrated that grain yield of cereals were decreased by 4.1% to 10.0% due to an increase of the seasonal average temperature by 1°C (Hatfield et al., 2011). Beside temperature, an increased variability of precipitation events even without changes in the total precipitation amount caused in drought stress as the relative length of drought periods increases, resulting in shorter grain filling periods and thus lower grain yields in barley (Lawlor et al., 1981 and Savin et al., 1997).

Climate change is likely to affect yield and yield quality not only directly due to impacts on crop physiology but also indirectly due to alterations in nutrient mineralisation and availability for crops, resulting in negative impacts on yield production (Hensen, 2008). Yield quality may be changed under multi-factorial climate change conditions as well (Wang & Frei, 2011). Crop quality is based on multi-faceted and complex processes involving biomass production, and partitioning and storage of assimilates. Besides long-term moderate warming, short periods of high temperatures (>30 °C) during sensible phases such as flowering or grain filling also result in negative impacts on grain yield quality of cereals (Passarella, Savin, & Slafer, 2008). Despite intensive research activities, there are still gaps in the understanding of factors controlling rate and duration of grain development, protein accumulation and starch deposition under changes in environmental conditions (Dupont & Altenbach, 2003).

Barley has been shown to reduce thousand grain weight under higher temperatures during the grain filling period (Lawlor et al., 1981 and Savin et al., 1996) as adaptation to warming occurs at the expense of metabolic processes and storage compound accumulation (Mangelsen et al., 2011). Accordingly, the decrease in grain yield is largely associated with the lower final starch concentration due to elevated temperature (Wallwork, Logue, MacLeod, & Jenner, 1998). On the other hand, increased protein concentration and thus a higher nutritional value have been found in association with temperature exposure (Stone, 2001). However, for malting barley this may be regarded as an adverse effect since low to moderate grain protein concentrations are preferred.

High temperature affects barley at various stages of growth. Floret numbers are greatly reduced at higher temperature of 24°C, in comparison to 18°C. Tillering is affected by day and night temperature regimes. High temperature also leads to etiolation and seedling mortality.

6.4.3 Climate Resilience of Barley Crop

Barley has good heat tolerance, but the heat must be dry heat. Barley does not do well in humid areas where there are many disease problems. Overall, barley is a crop that is best adapted to cooler, drier areas. The ideal condition for growing barley is moderately dry period for sowing, occasional showers during the growing season and good weather for harvesting. The growing period in the plains lasts for about 5 months. It is grown mainly in the northern plains for malting purpose. It is a hardy crop and is quite suitable for rain-fed drought prone areas and salt affected condition. In areas of good irrigation and medium fertility soils, malt barley of good quality can be produced.

It thrives best in areas having cool dry winters with low rainfall. The crop can withstand cool humid and warm dry climate but not humid climate which disfavours its growth, mainly due to prevalence of disease. It cannot tolerate frost at any stage of growth and incidence of frost at flowering and hailstorm at the complete grain development damage the crop. Rain during the growth period results in good growth of crop, but rain at maturity causes discolouration of the grains, thus rendering them unfit for malting. Intermittent drought during the growth period results in pre–mature ripening with high nitrogen content and shrivelled grains unfit for malting. Uninterrupted growth of the crop can give normal bold. Uniform moisture supply and bright sun – shine at the ripening are important for the production of bright kernels required by the malting industries.

It is well adapted to high altitudes with cold, short seasons. The species possesses moderate resistance to cold, it was found that barley grows best under cool, dry conditions, but can withstand hot, dry or cold and wet weather.

Barley requires cool weather during early growth and warm daily temperature of 23-25^{0}C is the best for sowing the crop. Late monsoon showers received during mid-August to the end of September are very valuable and the water thus conserved ensures enough moisture for satisfactory germination and plant stand. Barley crop does not perform well in excessive rainfall areas. Extremes of hot dry weather are undesirable. It is tolerant to moderately high temperatures provided humidity is low, but hot and humid climate is deleterious because of greater prevalence of diseases under such condition.

It is grown under rainfed, drought prone conditions and in regions where wheat cultivation is un-economical. A well distributed 200-250 mm rainfall can support barley crop, however, the crop does best with 400-500 mm annual rainfall. Barley being a long day plant would prefer a photoperiod of 10-12 and 12-14 hours during vegetative and reproductive stages, respectively.

6.5 Genetic potentiality advancement

Barley (*Hordeum vulgare* L.) is frequently being described as the most cosmopolitan of the crops, grown over the wide environmental range than any other cereal and it has been considered, as poor man's crop because of its low input requirement and better adaptability to harsh environments, like drought, salinity and alkalinity and marginal lands. Because of its hardiness, in many countries around the world, it is often considered the only possible rainfed crop under low input and stressful environments. It is grown by nearly 105 countries on about 48 million hectares. The area was decreasing around the world until mid nineties but after that there has been stabilization, though the productivity is improving.

The decline in area under barley can be broadly categorized in two phases. In first phase (the green revolution period) development of semi-dwarf wheat varieties with high yield potential made the farmers prefer wheat over barley. Since there was no such break through in barley yield potential, the shift happened for wheat crop from barley being the crops of the same season. In the second phase (post green revolution era), the barley area again decreased significantly because of development of irrigation network, further increase in wheat area as major food security crop, popularization /demand of more remunerative oilseed crops like mustard for rainfed conditions and less demand for industrial utilization of barley. These factors confined barley to marginal, problematic soils as a rainfed crop, further adding to the decrease in the production of barley.

Barley area, production and yield globally from 1981 to 2012

Year	Area (m ha)	Production (m t)	Productivity (t/ha)
1981-85	79.36	162.56	2.05
1986-90	76.05	171.6	2.26
1991-95	72.92	161.49	2.21
1996-00	58.76	141.82	2.41
2001-05	56.64	143.78	2.54
2006-09	55.61	145.11	2.61
2010-12	48.39	129.69	2.68

(**Source:** *FAOSTAT, © FAO Statistics Division 2012)*

Trends in the area and production of barley in India.

Year	Area (000 ha)	Production (000 t)	Productivity (q/ha)
1950-51	3113	2378	7.64
1960-61	3205	3819	8.80
1965-66	2640	2382	9.02
1970-71	2555	2784	10.9
1980-81	1807	2293	12.69
1990-91	970	1640	16.81
2000-01	777.5	1431	18.4
2009-10	623	1355	21.7
2010-11	699	1564	22.4
2011-12	643.4	1618	25.1

The increase in industrial demand of barley as raw material during early nineties resulted in hike in market prices and created a situation of short supply. In fact presently only about 25-30% of the total barley production is used in the manufacture of malt and malt extract, which is further utilized for brewing, distillation, baby foods, cocoa-malt drinks and medicinal syrups. Rest of the production is utilized as cattle feed, cereal food and in preparation of local beverages in the tribal areas. The available six-row barley possessed higher husk and less carbohydrate resulting in poor malting quality. This was mainly because of poor management of the crop as well as the inability of cultivars to bear the optimum management. Thus the continuous decline in barley area and production as well as reduced preference of farmers to grow barley under better management had triggered a shortage for good quality grain for malting in mid nineties. The Government of India has issued license to several new breweries, which created a demand for international quality malt as raw material for the breweries looking for the collaboration/ competition with multinational companies. The same trend is still continues and India is currently having highest growth rate/ increase in demand for beer in the world and several multinational companies have already established their set up in country to cater this demand. Further to promote the cultivation of malting type cultivars these companies have initiated “Contract Farming” in states like Punjab, Haryana and Rajasthan to ensure continuous supply of the raw material (malt barley grain) to meet the growing demand of malt for brewing and confectionary items.

A large number of improved varieties with resistance to diseases were developed for feed and food purposes for different production conditions/ zones. The latest feed barley variety developed in the series is BH902 by Hisar centre. However, with the recent changes in climate conditions the program will have to continue working hard to address the new threats of change in disease dynamics and drought & heat stress to maintain / make further improvement in yield levels.

Barley varieties released during recent years for feed purposes

Cultural Practices	Variety	Year	Area of adaptation	Developed by
Irrigated	PL751	2006	Central zone	PAU Ludhiana
	BH 902	2010	NWPZ	CCS HAU, Hisar
	Jawahar Barley 1	2009	Madhya Pradesh	COA, JNKV, Rewa
Rainfed (Northern Hills)	RD2660 Rainfed	2006	NWPZ	ARS, Durgapura
	BHS380	2010	Northern Hills Zone	IARI, RS, Shimla
	UPB1008	2011	Northern Hills	GBPUA&T, Pantnagar
	PRB502	2009	Uttarakhand	GBPUA&T, Pantnagar

Barley improvement for malting purpose:

Presently about 20-25% of the total barley production is used in the manufacture of malt, which is utilized for brewing, distillation, baby foods, confectionaries cocoa-malt drinks and medicinal syrups. The malt utilization patterned has also changed in recent years, with an increase in proportion of malt being used for brewing and decrease in distillation. The current estimates indicate that now approximately 30% malt is used for energy drinks/pharmaceuticals & confectioneries, 8% for whiskies and balance (around 60-62%) are used by breweries.

The research on barley improvement dates back to 1920’s and 1930’s in India, when by pure line selection a number of improved barley varieties like C 251, T-4, T-5 were developed (ICAR 1961, Vasudeva, et. al. 1979). Through these varieties were not aimed for malting, but because of their good grain type, were also utilized for malting. Amongst these, C254 was exported to England for industrial utilization (Roberts and Singh, 1951). The research efforts on malt barley started in 1969-70, when Clipper was introduced from Australia to fulfill the industrial demands in northern plains of India. It was a two-row, semi winter type malt barley with late maturity and therefore could not become popular. During 1974-75, three two-row barley introduction (Golden-Promise, Universal, and Midas) from U.K. were evaluated under the AICBIP at four locations, but they also could not match the yield levels of six-row Indian barley cultivars.

In order to fulfill the demand of better malt type barley indigenously it was planned to first screen/ evaluate the available cultivars for their acceptability as malt barley by the industry. The grain samples of the improved six-row barley cultivars along with some old released varieties were provided for preliminary evaluation to M/S Imperial Malts Pvt. Ltd.

Gurgaon, in 1988. It was found that varieties like RD37, RD57, RS6, Bilara 2 and C 138 could be utilized for malting, however, all the them were old tall barley for rainfed cultivation and could not withstand better management. All other improved high yielding cultivars were not found suitable for malting, because of several undesirable grain and malt characters.

Germplasm introduction, mostly the two-row type from ICARDA, Syria; CIMMYT, Mexico; Australia, Denmark and Argentina were made and evaluated under multi location yield trials and nurseries during 1988-1993. One of such introduction, "ALFA93" a two row, good malt type barley variety was released by CVRC in 1994 for commercial cultivation in North Western Plains Zone under irrigated timely sown conditions. It performed satisfactorily in NWPZ (Punjab, Haryana, Rajasthan and Western U.P.) with 36.8 q/ha mean grain yield. In 1997 Rekha (BCU73), another two-row, semi-dwarf, high yielding malt barley introduction from Australia (via ICARDA nursery), with early maturity was released by CVRC for commercial cultivation in entire barley growing area of the country except the Northern Hills. It has bold uniform grains and can be grown over a much wider area of adaptation. Some of the good six-row barley cultivars released during the period, such as RD 2503 (NWPZ), K 551 (NEPZ/NWPZ) and DL 88 (Peninsular Zone) for cultivation under irrigated timely sown conditions were also recommended to be used as malt barleys.

Malt barley varieties released recently is as under:

Two-row barley varieties released in India for malting and brewing purposes

Variety	Year	Production Condition	Area of Adaptation	Developed at
DWRUB52	2007	Irrigated (TS)	NWPZ	DWR Karnal
RD2668	2007	Irrigated (TS)	NWPZ	ARS (RAU) Durgapura
DWRB 73	2011	Irrigated (LS)	NWPZ	DWR Karnal
DWRUB 64	2012	Irrigated (LS)	NWPZ	DWR Karnal
DWRB 91	2013	Irrigated (LS)	NWPZ	DWR Karnal
DWRB92	2013	Irrigated (TS)	NWPZ	DWR Karnal

In order to widen the scope of malt barley cultivation in the late sown conditions of northern plains in rotation to cotton, pearl millet, sorghum, maize and sugarcane crops, a new varieties, DWRB73, DWRB 91 and DWRUB 64 has been recently released for commercial cultivation. These varieties gives good grain yield with acceptable malting quality under late sowings up to mid December and will help in increasing barley cultivation in such areas.

These varieties have performed very well in farmer's field and gave yield comparable to best six row checks under optimum management conditions. These varieties are now being utilized by private companies for "Contract Farming" in Punjab, Haryana and Rajasthan to fulfill their increasing demand of raw material for malting. The farmers are also now convinced about their yield potential as well as the assured marketing at premium price by the industry.

Barley improvement for salinity tolerance

Barley is known for its inherent tolerance to salinity and alkalinity as compared to other cereals. It has a good potential for problematic soils where otherwise it's very difficult to grow crop in winter season. In order to meet the demand for such areas barley centers like Faizabad, Kanpur, Durgapura and Hisar are evaluating new varieties as they have good facility for salinity screening.

Variety	Year	Production Condition	Area of Adaptation	Developed at
RD 2552	1999	Irrigated (TS)	NWPZ, NEPZ	ARS(RAU), Durgapura
NDB1173	2004	Irrigated (TS)	NWPZ, NEPZ	NDUA&T, Faizabad
RD 2786	2013	Irrigated (Salinity)	NWPZ, NEPZ	ARS(RAU), Durgapura

Dual purposes barley for semi arid areas

Barley grain has been traditionally used as animal feed and grain crop for human consumption in India. In recent years due to increasing scarcity of green forage availability in the arid and semi arid region, it was observed that barley can be utilized as an alternative source of green forage in the drier parts of states like Rajasthan, Haryana, Punjab, M.P. and U.P. Also in case of hills, most of the farmers are growing barley in apple orchards mainly for utilization as green forage. It was found that barley crop can be given one cut (at 50-55 days after sowing in plains and 70-75 days after sowing in hills) for green forage and the regenerated crop can be utilized for grain purposes. A new series of yield trials was initiated from 2003-04 crop season for dual-purpose barleys in plains and hills zones to identify suitable genotypes. Already released feed type varieties RD2035 and RD2552 have been found equally good to be used as dual purpose type. Two more new varieties (RD2715 for central zone and BHS380 for NH zone) have been released by CVRC as dual purpose barley as forage cum grain crop.

Dual purpose barley varieties released in India

Variety	Year	Production Condition	Area of Adaptation	Developed at
RD2715	2008	Irrigated	Central zone	ARS, Durgapura
BHS380	2010	Rainfed	Northern Hills	IARI, RS, Shimla
RD2035	1994*	Irrigated	NWPZ	ARS, Durgapura
RD2552	1999*	Irrigated	NWPZ	ARS, Durgapura

**These varieties were released as grain type earlier but recently observed as also good for dual purposes*

However, there is a need to continue working on this area to develop better variety to be used as dual purpose barley. There is also a need for evaluation of the forage quality traits to improve the overall suitability as green forage. Thus barley can serve as supplementary crop for augmenting the green forage demand in the arid/ semi arid areas of northern plains under limited irrigations and in hills under rainfed conditions. It also gives satisfactory levels of grain yield from the regenerated crop, which can also be utilized as feed for cattle feed or for human food.

Status and scope of transgenic and genomic in Barley

A broad spectrum of resources has been developed during the last two decades (http://barleygenome.org) to facilitate the systematic analysis of the barley genome. Recent advances made in barley genomics mainly include integrated physical, genetical and functional sequence assembly of the barley genome, the rapid accumulation of EST sequence data, growing numbers of studies on transcriptome, proteome, and metabolome, new modeling techniques, availability of genome-wide knockout collections as well as efficient transformation techniques. This has been assisted by a large number of mapped molecular markers, BAC libraries, mutant collections, DNA arrays, and enabling large scale production of doubled haploids and efficient transformation protocols. The team International Barley Genome Sequencing Consortium (IBSC) has constructed the high-resolution draft DNA sequence that has provided the functional portions of the genome, revealing structure and order for most of the genes. These developments have paved the way for a comprehensive functional analysis and understanding of gene expression networks linked to agronomically and commercially important traits like higher yields, improved pest and disease resistance and enhanced nutritional value. This will, therefore, streamline efforts to improve barley production through breeding for varieties better able to withstand pests and disease and deal with adverse environmental conditions such as drought and heat stress.

Following the success of transgenic maize and rice, methods have now been developed for the efficient introduction of genes into barley. Progress in stable genetic transformation of barley ensures a potential for improvement of its agronomic performance or use of barley in various biotechnological and industrial applications. Recently, barley grain has been successfully used in molecular farming as a promising bioreactor adapted for production of human therapeutic proteins or animal vaccines. The systematic efforts were made for genetic engineering of barley to improve seed quality traits for malting. Malting improvement has been addressed by altering the expression of hydrolytic enzymes related to the degradation of storage products such as starch (*á* and ß-amylases) and cell wall components. In another approach, several enzymes such as xylanase, glucanase, endo-, and exoprotease were over expressed in transgenic barley grains and preferably the enzyme mix necessary for malting process are provided by transgenic seeds. Protein engineering has been used to produce thermostable 1, 3; 1, 4ß-glucanases in transgenic barley grains. Such grains can be used to enhance the feed quality of barley for poultry. Overall, barley represents a promising tool for both agricultural and biotechnological transgenic approaches, and is considered an ancient but rediscovered crop as a model industrial platform for molecular farming. Contrary to other cereals, currently no transgenic barley variety is commercially available, excluding the lines used for molecular farming, which are in property of several biotech companies.

As far as India is concerned, only few molecular studies have been reported so far in barley. With the growing demand of malt barley for commercial purposes, there is a huge scope for malt barley in India. Therefore, there is a dire need of long-term investments in the public sector in form of consortium or network program for barley to reap benefits of available molecular information and latest technologies in barley genomics and transgenic. It is now time to use interdisciplinary approaches to tackle the serious challenges of abiotic and biotic drought stresses and malt quality traits in barley. The scientific community and science policymakers should consider integrated biotechnology approaches together with new genomics and conventional breeding for barley improvement.

6.6 Recommended package of practices

Till early sixties agronomic investigations on barley in India centered mostly on varietal evaluation and mixed cropping trials. With initiation of All India Coordination Project on Barley in late sixties, experiments on most of the important agronomic aspects like seed rate, method and time of sowing, fertilizer and irrigation requirement of barley were undertaken. During early seventies more emphasis was laid on dry land barley research and later a new line of research on malt barley management was undertaken. All these efforts led to useful recommendations for better crop management. Later, the research efforts were diverted to solve the specific and location oriented problems in barley production. The problems in hulless, hulled and malt barley are different from each other. Not only this, the problems and limitation in irrigated, dry land, saline/ alkaline, acidic, single and double cropped situations, timely and late sown conditions are quite different from each other. Research on resource conservation techniques and input management was initiated in 2006-07. Varieties were evaluated for different tillage options. Inputs like seeds, fertilizer and irrigation were optimized for new genotypes. Investigations in production technologies for dual purpose barley were initiated during 2005-06 and recommended date/stage of cutting for fodder, fertliser application (dose and time), irrigation and varieties for the specific purpose.

The barley resource management trials are carried out at 14 locations covering the states of Himachal Pradesh, Uttarakhand, Punjab, Haryana, Rajasthan, Uttar Pradesh and Madhya Pradesh (table 11). Four centres in the Northern Hills zone (Almora, Bajaura, Malan and Shimla), six centres in the North Western Plain Zone (Agra, Durgapura, Hisar, Ludhiana, Karnal and New Delhi) and four centres in the North Eastern Plain Zone (Faizabad, Varanasi, Kanpur and Rewa) were involved in the evaluation programme.

Timely sowing of barley ensures good return from the crop including maximum use of conserved moisture and to avoid high temperature. Delayed sowing reduces the grain yield per unit area and produces poor quality grain, not suitable for malting. These problems can be overcome by using varieties recommended for late sowing. The different sowing times of barley at various agro-climatic zones have been standardized after coordinated experiments over the years.

Recommended sowing dates for different zones

Zone	Sowing Time	Recommended dates
Northern hills zone	Normal	25th Oct. to 11th Nov.
	Late	25 th Nov. to 0Ist Dec
North western plains zone	Normal	05 th Nov. to 15 th Nov
	Late	10 th Dec. to 16 th Dec.
North eastern plains zone	Normal	15 th Nov. to 25 th Nov
	Late	10 th Dec. to 16 th Dec.
Central zone	Normal	12 th Nov. to 18 th Nov
	Late	02 th Dec. to 10 th Dec.

The seed rate of barley depends upon its test weight, spacing, sowing time and method as well as soil fertility status. Recent agronomic experiments suggest that seed rate of 100 kg/ha for irrigated timely sown conditions in medium fertile soil and 120 kg/ha for irrigated or rainfed late sown conditions in poor soils is optimum. The seed of barley should be sown to a depth of 5-7 cm at a distance of 22-23 cm. In case of two-row malt barley varieties, line to line spacing should be 18cm to get optimum grain yield and quality. In early sixties recommendations, fertilizer application to the barley crop was very low. Looking into the cultivation of barley under optimum management conditions for malting and feed purposes the recent experiments have indicated that higher dosages of N fertilizers can be applied. In order to reduce use of chemical fertilizer and sustainable production, 5 t FYM + 75 % of chemical fertilizer can be used in barley.

Barley is a fast growing crop and generally weeds may not compete with crop if proper crop stand is maintained. However, if required, isoproturon may be used for control of grassy weeds including the *Phalaris minor* and for broad leaf weeds 2,4-D or metsulfuron can be used. The common wheat herbicides like Leader and Pumasuper etc. should not be applied on barley as some of them may cause heavy losses in barley. Recently Pinaxaden (Axil) has been found effective against the isoproturon resistant types of *Phalaris minor* in barley.

Revised recommendations of the fertilizer application in barley

Zone/State	**Production conditions**	**N : P : K (Kg/ha)**	
		Earlier recommendations	**Recent recommendations**
Northern Hill Zone	Rainfed	20:20:0	40:20:20
NWP Zone and NEP Zone	Irrigated timely sown	40:20:0	60:30:20 (feed barley) 90:40:20 (malt barley)
	Irrigated Late sown	40:20:0	60:30:20
	Rainfed	20:20:0	40:20:20
Dual Purpose in Plains and Hills	Irrigated/ rainfed	-	75:30:20 (plains) 60:30:20 (hills)

Barley for green forage and grain can be grown in semi arid and arid climatic conditions where no other green forage is available in winter months due to shortage of irrigation water or low rains. The new varieties have been developed zone wise for dual purpose barley. The time of cut for green fodder was optimized and cutting at 55 days after sowing was found optimum in plains and 70 days or first node stage in hills. Multi location experiments resulted that seed rate of 120 kg/ha and fertilizer dose of 75N:30P:20K kg/ha are optimum for dual purpose barley. Dual purpose barley provides nutrition rich green fodder for the livestock at the time of scarcity and at the same time also provides acceptable quality grain for human consumption. On an average, 180-240 and 24-35 q/ha of green fodder and grains, respectively can be produced from dual purpose barley crop. Recommended package of practices of Barley by ICAR is given in **Table-53.**

Table-53: Recommended package of practices of Barley by ICAR

S. No.	Operation		
1.	**Time of Sowing** Rabi		
	Northern hills zone	Normal	25th Oct. to 11th Nov
		Late	25 th Nov. to 0Ist Dec
	North western plains zone	Normal	05 th Nov. to 15 th Nov
		Late	10 th Dec. to 16 th Dec
	North eastern plains zone	Normal	15 th Nov. to 25 th Nov
		Late	10 th Dec. to 16 th Dec.
	Central zone	Normal	12 th Nov. to 18 th Nov
		Late	02 th Dec. to 10 th Dec.
2.	**Method of Sowing** Manual (%) 40%		
	Mechanised (%) 60% (By Drill)		
3.	**Seed** Seed Rate 100kg/ha		
	Plant to plant distance 2-3 cm		
	Ideal plant population/ha 2170000-2200000		
	Seed treatment		
	Fungicides (Name & Dose) Carboxin 37.5%+ Thiram 37.5% WS		
	Bio-fertilizer (Name % Dose) -		
4.	**Fertilizer dozes (kg/ha)** **Rabi/Summer** N:P: K@60:30:20 (Feed barley) and 90:30:20 (malt barley)		
	Manures FYM@5t/ha		
5.	Name of major weeds –Chenopodium, Rumex, *Phalaris minor, Cornopus didymus*, **Weeds Control** Control Measures Pendimethilin (Stomp 30 EC) 3333-4950 g/ha* in 400-500 liter of water 2-3 days after sowing or Isoproturon (Arelon 75 WP) 1333 g/ha* at 30-35 days after sowing using 400-500 liters of water or Pinaxaden (Axial 5 EC) 700-800 g/ha* at 30-35 days after sowing using 400-500 liters of water. **Product dose*		
6.	**Disease/Pest Management Name of major disease/pest** Yellow and brown rust, loose and covered smut, leaf blight and aphidsControl Measures one spray of Propiconazole 25EC (Tilt 25 EC) or Tebuconazole 250 EC (Folicur 250 EC) or Triademefon (Bayleton 25 WP) @ 200 ml of fungicide mixed with 200 liter of water should be sprayed in one acre crop. To control aphids apply Confidor (Imidacloprid 200 SL)@20g a.i./ha		
7.	**Harvesting & Thrashing** Time month of April after shading of leaves (before the shattering of spikes nearly @ 12% moisture)		

6.7 Cropping system

It is generally grown in rotation with pearl millet (bajra), maize, rice, cotton, groundnut, green gram and moth bean in different parts of the country. Researches have shown the possibility of double cropping in dryland areas by growing short-duration (60-65 days) fodder legumes (cow pea, cluster bean etc.) during rainy (Kharif) season, followed by the dryland crop of barley. Benefit from preceding fodder legume is equivalent to 40 Kg N/ha applied to barley crop grown after the previous non-legume crop of pearl millet. Double cropping with barley is practiced under assured soil moisture. The role of continuous crop cover on saline soils to keep the salinity away is well established. Under saline-cum-shallow water-table conditions, a crop rotation with rice-barley-cowpea (fodder) is highly profitable in keeping the surface salinity under control. On soils infested with nematodes, rotation of barley with non-host crops, e.g. sunflower, for at least 1 to 2 years would reduce the nematode population. At higher elevations, wherever barley is harvested by July-August, an early maturing buckwheat is grown as a second crop. In Kashmir valley, paddy is the main Kharif crop and the fields remain fallow during rabi. Barley can fit well in rotation with paddy in this region. Due to its extreme adaptation and inherently hardier nature, barley can be grown in mixture with other rabi crops, e.g. wheat, gram, peas and lentil, thus it provides insurance cover under rainfed conditions.

6.8 Crop products

Barley grain is used as feed for animals, malt for industrial uses and for human food. Barley straw is used as animal feed in many developing countries including India. Barley straw is also used for animal bedding and as cover material for hut roofs. Barley is also used for green forage and either directly fed to the animal or used for silage. It also has immense potential as quality cereal especially for nutritional and medicinal point of view. Malt is the second largest use of barley and malting barley is grown as a cash crop in a number of developed and developing countries including India. The utilization of barley for malting and brewing industry has picked up recently with an increase of consumption of beer and other malt based products in many countries including India. In India, barley produce is used for malt and malt extract, which is further utilized for brewing, distillation, baby foods, cocoa-malt drinks and medicinal syrups. In recent years the proportion of barley used in brewing has gone up as compared to ten years back as demand for beer is on rise in the country. In developed countries barley is considered as a functional food and used in many bakery products and recipes. In India, its utilization as food crop (mainly hull less type) is restricted to the tribal areas of hills and plains. The barley products like “Sattu” (in summers because of its cooling effects on human body) and missi roti (for its better nutritional quality) have been traditionally used in India

6.9 Constraints impeding barley production in the country

Over all analysis of constraints in different zone clearly indicated that aphid, *Chenopodium album*, *Phalaris minor,* termite, *Convolvulus arvensis*, *Rumex dentatus* (Jungli Palak), Small land holdings, Leaf blight, Loose smut, Aphid and high temperature at maturity were identified as major constraints affecting barley production and productivity of the country.

6.10 Impact on crop with respect to uptake of nutrients, soil health and underground water

6.10.1 Nutrient Requirement

Actual uptake and removal will vary with crop yield, crop variety, soil fertility and from year to year. Accurate removal values can only be determined by laboratory analysis. Crop uptake of nutrients is affected by soil and climatic conditions. As per early sixties recommendation, fertilizer application to the barley crop is negligible and its requirement depends upon soil test report, climate and variety. Nitrogen is essential for high yield, particularly on soils with low organic content but the excess use of nitrogen cause lodging, adversely affects the yield. On an average, phosphorus and potassium requirement of barley is 30 and 20kg/ha which are adequate to maintain soil fertility. It was reported that split application of potassium (with planting and at 8 weeks after planting) can decrease the risk of lodging. With the increase in yield over the last couple of years, mainly due to genetic improvement, improved production practices and optimum irrigation scheduling, it appears that a total nitrogen application of 90 kg/ha for malt barley, depending on the soil texture and rotation system seems to be sufficient for optimum yield and quality. An additional 20 kg N/ha is also recommended on very sandy soils, where leaching of nitrogen is a major problem. Split application of nitrogen fertilizer is more important under overhead irrigation and sandy soils than under flood irrigation and heavy clay soils. A split of half of the total nitrogen with planting and the rest half 5- 6 weeks after emergence, seems to give the best results. On very sandy soils where leaching is a problem and a history of low nitrogen content in the grain is experienced, the topdressing can be applied at a later stage but not later than the flag leaf stage. The agronomic practices that were most beneficial for malt barley production are early seeding and application of N fertilizer at appropriate rates.

6.10.2 Soil Health

The soil should not be very fertile as the crop lodges very severely and drastic yield loss is observed. It is susceptible to water logging. Sandy to moderately heavy loam soils of Indo-Gangetic plains having neutral to saline reaction and medium fertility are the most suitable type for barley cultivation. However, it may be grown on variety of soil types, viz, saline, sodic and lighter soils. Acidic soils are not fit for barley cultivation, as such.

6.10.3 Underground water

Besides affecting crop yield and soil physical conditions, irrigation water quality can affect fertility needs, irrigation system performance and longevity, and how the water can be applied. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity.

6.10.4 Salinity Hazard

The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity (ECw). The primary effect of high ECw water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire “pure” water, usable plant water in the soil solution decreases dramatically as EC increases. Actual yield reductions from irrigating with high EC water varies substantially. Factors influencing yield reductions include soil type, drainage, salt type, irrigation system and management. The amount of water transpired through a crop is directly related to yield; therefore, irrigation water with high ECw reduces yield potential. Beyond effects on the immediate crop is the long term impact of salt loading through the irrigation water. Water with an ECw of only 1.15 dS/m contains approximately 2,000 pounds of salt for every acre foot of water. You can use conversion factors in Table 3 to make this calculation for other water EC levels. The yield reduction of barley is 0, 10, 25 and 50% if the ECw of irrigation water is 5.3, 6.7, 8.7 and 12 dS/m at 25^{oC} respectively.

6.10.5 Sodium Hazard

Infiltration/Permeability Problems: Although plant growth is primarily limited by the salinity (ECw) level of the irrigation water, the application of water with a sodium imbalance can further reduce yield under certain soil texture conditions. Reductions in water infiltration can occur when irrigation water contains high sodium relative to the calcium and magnesium contents. This condition, termed "sodicity," results from excessive soil accumulation of sodium. Sodic water is not the same as saline water. Sodicity causes swelling and dispersion of soil clays, surface crusting and pore plugging. This degraded soil structure condition in turn obstructs infiltration and may increase runoff. Sodicity causes a decrease in the downward movement of water into and through the soil, and actively growing plants roots may not get adequate water, despite pooling of water on the soil surface after irrigation. Susceptibility ranges for barley crop to foliar injury from saline sprinkler water are 231-460 (mg/L) for Na concentration and 351-700 (mg/L) for Cl concentration.

pH and Alkalinity: The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4. Abnormally low pH's are not common in Colorado, but may cause accelerated irrigation system corrosion where they occur. High pH's above 8.5 are often caused by high bicarbonate (HCO3-) and carbonate (CO32-) concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution. As described in the sodium hazard section, this alkaline water could intensify the impact of high SAR water on sodic soil conditions. Excessive bicarbonate concentrates can also be problematic for drip or micro-spray irrigation systems when calcite or scale build up causes reduced flow rates through orifices or emitters. In these situations, correction by injecting sulfuric or other acidic materials into the system may be required.

6.10.6 Nitrogen

Nitrogen in irrigation water (N) is largely a fertility issue, and nitrate-nitrogen (NO3-N) can be a significant N source. The nitrate ion often occurs at higher concentrations than ammonium in irrigation water. Waters high in N can cause quality problems in crops such as barley and sugar beets and excessive vegetative growth in some vegetables. However, these problems can usually be overcome by good fertilizer and irrigation management. Regardless of the crop, nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 ppm NO3-N in irrigation water.

6.10.7 Barley varieties tolerance to abiotic stresses

The phenotypic performance of a variety is determined by its genotype, environment and the interaction of both the factors. The environment of a variety may be simply defined as sum total of all the factors other than the individual concerned. The various factors of environment are called biotic or abiotic depending upon their biological/non-biological nature.

Abiotic stresses are the primary sources of yield losses. These include drought, frost, cold, high temperature, low temperature, chilling, water lodging and saline/ alkaline soils. The stresses make the crop less productive with unstable performance. Drought is the main abiotic factor as it affects 140 million hectares (68% of Net sown area) cropped area and saline/alkaline soils cover 6.73 million ha area in India which reduces the crop production and productivity. Climate change also plays a critical role for abiotic stresses such high temperature, low temperature, altered rainfall patterns, floods, greater severity and frequencies of extremes events. These stresses may decline the crop yield at different stages such as water lodging at vegetative stage, cold sensitivity at flowering stage, terminal drought during grain filling stage and salinity/alkalinity throughout the crop period.

To avoid the yield loss by above stresses, tolerant/resistant varieties of barley have been released by different institutes/Universities-

Barley Varieties suitable for stress tolerent

S.No.	Name of varieties	Year of release	Released by	Developed at	Specific traits
1.	K-70	1965	Deptt. of Agri. U.P.	CSA Kanpur	Recommended for flooded areas of eastern U.P.
2.	RATANA	1970	CVRC	I.A.R.I., New Delhi	Tolerant to saline and alkaline conditions.
3.	RBD 1	1971	SVRC	Durgapura	Lodging resistance
4.	HIMANI	1973	CVRC	IARI, Shimla	Tolerance to drought and shattering
5.	Bilara-2	1978	SVRC	Durgapura	Suitable for saline sodic soils
6.	K-141	1982	SVRC	CSA Kanpur	Suitable for saline alkaline areas
7.	K-409	1997	SVRC	CSA Kanpur	Suitable for dry areas
8.	RD 2552	1999	CVRC	Durgapura	Suitable for saline soil
9.	BHS 352	2003	CVRC	IARI, Shimla	Tolerance to cold
10.	NDB 1173	2004	CVRC	NDUA&T, Faizabad	Suitable for saline-alkaline soils

6.11 Major problem associated with storage of grains

The biotic and abiotic factors that cause considerable losses (20%) of stored foodstuffs in India. Quality and germination capacity may deteriorate over 14.0 per cent moisture. Ideal storage conditions can be maintained by means of natural aeration or frequent turning of the grain in the bin. Seed germination of the hulled cultivars was not affected at 60% RH and was decreased by around 10% at 75% RH, whereas the germination of hull-less cultivars was markedly decreased at 75% RH.

The insects most injurious to stored grain are the *Coleoptera Rhyzopertha dominica*, *Sitophilus oryzae*, *Tribolium castaneum* and *Trogoderma granarium*, but *Sitotroga cerealella, Laemophloeus minutus [Cryptolestes pusillus*] and *Liposcelis* sp. were also observed occasionally. It was found that grain with over 0.5% kernel infestation was unfit for milling, and that wheat flour containing over 10 mg uric acid/100 g (from insect contamination) was unacceptable to consumers. The Khapra beetle is considered to be the most serious pest of stored products under hot dry conditions. Complete destruction of grain and pulses may occur in a very short time. In humid climates, the rates of increase of its competitors are so much greater that it has difficulty in establishing itself. Grain weevil; *Sitophilus granarius* L is a serious pest of stored grains. Cause flour to become prone to moulding and will also turn the product grey.

Lesser Grain Borers are primary pests of grain and will therefore attack undamaged grain rendering it susceptible to attack by secondary pests. Both the adults and larvae feed on the grain creating floury dust and potentially leaving little but empty husks. The adults are active and may infest a large number of kernels whilst the larvae penetrate kernels and develop within the grain.

The beetles do cause damage by feeding but probably cause more problems by contaminating the grain. The red flour beetles cannot feed on whole, undamaged grain; they are, however, often found among dust, fines and dockage. Large numbers of dead bodies, cast skins and fecal pellets, as well as liquids (quinones), can produce extremely pungent odours in grain.

Among seed mycoflora of cereals and aflatoxin contamination, *Aspergillus flavus* was the most frequently isolated species under various storage systems. The amount of aflatoxin contaminating the stored cereal samples was 430-2830 p.p.b. and the greatest amount was detected in cereals stored in kothi made of mud and rice husk. Aflatoxin content levels in barley ranged from trace levels in samples from iron bins to 240 p.p.b. in samples from gunny bags. Bavistin [carbendazim] gave the best control of storage fungi while maintaining a high percentage of seed germination. Phosfume [aluminium phosphide] was the best of 3 fumigants and calcium propionate the best of 3 organic acids.

Damage by stored-grain insects usually goes unnoticed until the grain is removed from the storage facility. Regular monitoring will help to ensure that grain quality will be maintained at the highest level possible. A regular monitoring program should be continued until the grain leaves the farm. Managing stored grains requires the use of various techniques to ensure that the quality of the grain entering the storage facility does not deteriorate over time. These measures include: the use of sanitation; storing sound, dry grain; managing temperature and aeration; and using chemical protectants, regular, sampling, and fumigation. Bin facilities play an important role in deter-mining whether grain quality is maintained and should be inspected regularly.

6.12 Researchable issues

Research priorities decided by AICRP, ICAR for 12 Plan

Crop Improvement

- Malt Barley improvement for timely & late sown conditions under optimum management.
- Barley improvement for feed and dual purposes in rainfed & restricted irrigation conditions.
- Incorporation of diverse resistance for stripe & leaf rusts, leaf spot and aphid.
- Use of MAS in resistance breeding and malting quality improvement.
- Germplasm enhancement through pre breeding involving wide crosses and winter x spring hybridization.
- Increased germplasm utilization and exchange

Crop Protection:

- Diversity of resistance sources for rusts (stripe and leaf) and leaf blight in barley.
- Molecular diagnostics of pathogens (race identification) and host resistance.

Quality Evaluation & Basic Research

- Biochemical basis of malting and nutritional quality in Indian barley
- Forage quality analysis in dual purpose barley.
- Use of NIR and other new techniques in quality evaluation.

Resource Management

- Optimization of resource conservation technique for barley
- Restricted irrigation application in feed barley.
- Nutrient management in dual (feed and fodder) purpose, saline-sodic soil conditions
- New agronomy for malt barley barley-fertility x water x plant population.

7. Important Websites

Name of organization	Website URL
International	
Food and Agriculture Organization	http://www.fao.org
International Crops Research Institute for Semi-Arid Tropics (ICRISAT)	http://www.icrisat.org
International Food Policy Research Institute (IFPRI)	http://www.ifpri.org
International Development Research Centre, Canada	http://www.idrc.ca
CIMMYT, Apdo. Postal 6-641 06600 Mexico, D.F., MEXICO	www.cimmyt.org
International Institute of Tropical Agriculture IITA PMB 5320, Ibadan, Oyo State, Nigeria	http://www.iita.org
National	
Department of Agriculture & Cooperation, Ministry of Agriculture	http://www.agricoop.nic.in http://www.seednet.gov.in
India Council of Agriculture Research (ICAR)	http://www.icar.org.in
Indian Agriculture Research Institute.	http://www.iari.res.in
Directorate of Sorghum Research, ICAR, Hyderabad	www.sorghum.res.in
Directorate of Wheat Research, ICAR, Karnal (Haryana)	http://www.dwr.in/
Directorate of Maize Research, ICAR, New Delhi	www.dmr.res.in
All India Coordinated Pearl millet Improvement Project, ICAR	http://www.aicpmip.res.in
All India Coordinated Small Millets Improvement Project (AICSMIP), Bengaluru	http://www.smallmillets.res.in
Central Food Technological Research Institute (CFTRI), Mysore (Karnataka)	http://www.cftri.com
Directorate of Millets Development	http://www.dmd.dacnet.nic.in
Directorate of Agricultural Marketing and Inspection, Ministry of Agriculture	http://www.agmarknet.nic.in
Millet Network of India, Hyderabad	http://www.milletindia.org

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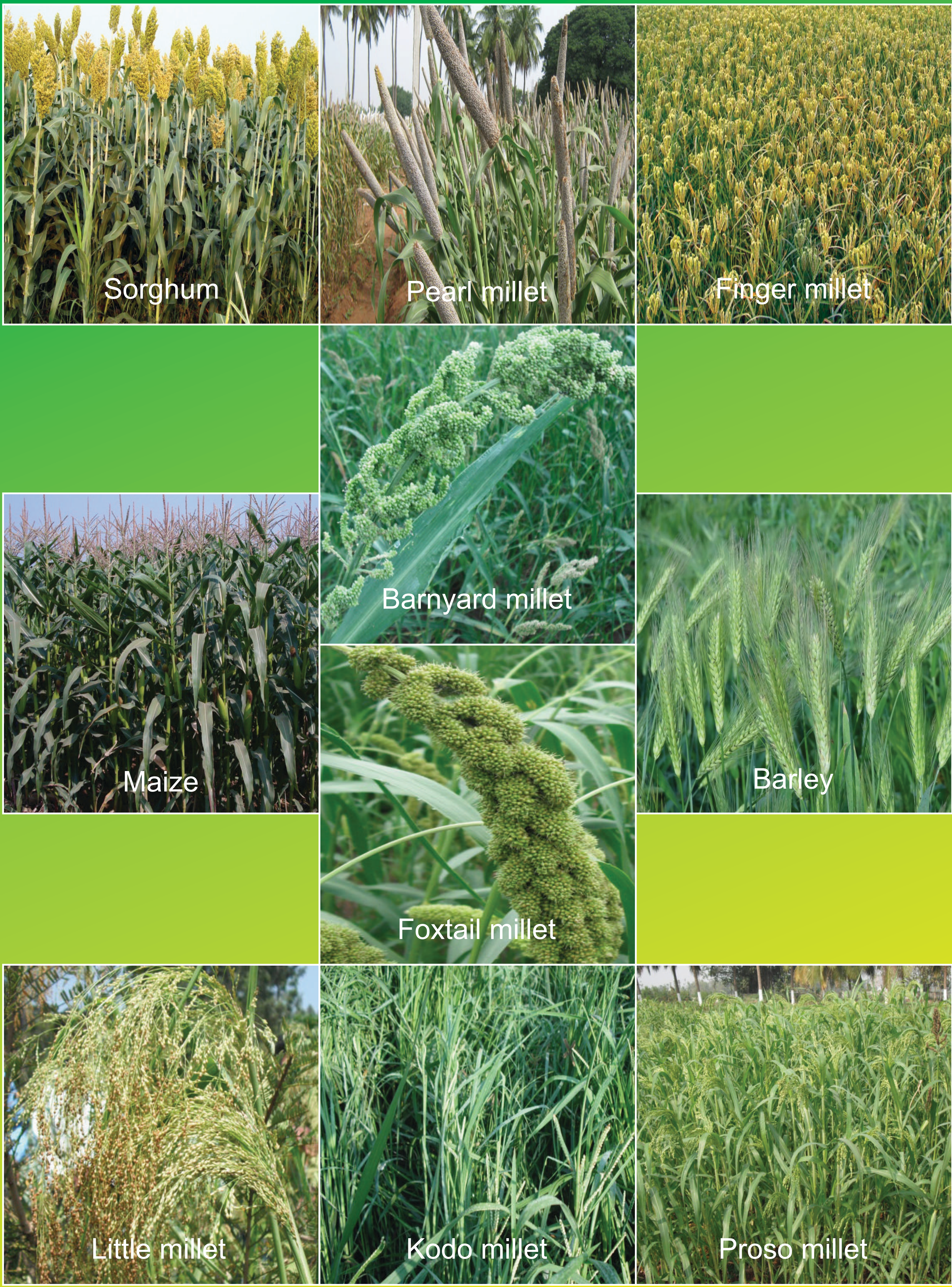
Sorghum
Pearl millet
Finger millet
Barnyard millet
Maize
Barley
Foxtail millet
Little millet
Kodo millet
Proso millet