

Cereals and Millets



Rice

(*Oryza sativa* L.)

Rice is the staple food of more than 60% of the world's population. It is the staple food of most of the people of South-Eastern Asia. About 90% of all rice grown in the world is produced and consumed in the Asian region. In India, rice is the most important and extensively grown food crop, occupying about 43.66 million hectares of land.

Rice occupies a pivotal place in Indian agriculture and is the staple food for more than 70% of population and a source of livelihood for about 120 to 150 million rural households. It accounts for about 40% of total foodgrain production and 43% of cereals production in the country.

Rice is primarily a high-energy or high calorie food. It contains less protein than wheat. The protein content of milled rice is usually 6 to 7%. Rice, however, compares favourably with other cereals in amino acids content. The biological value of its protein is high. The fat content of rice is low (2.0 to 2.5%) and much of the fat is lost during milling. Rice contains a low percentage of calcium. Rice grain contains as much B group vitamins as wheat. Milled rice loses valuable proteins, vitamins and minerals in the milling process during which the embryo and the aleurone layer are removed. Much of the loss of nutrients can be avoided through parboiling process.

The by-products of rice milling are used for a variety of purposes. Rice bran is used as cattle and poultry feed. Rice hulls can be used in manufacture of insulation materials, cement, cardboard and as a litter in poultry keeping. Rice straw can be used as cattle feed as well as litter during winter.

ORIGIN AND HISTORY

Rice cultivation probably dates back to the antiquity and has probably been the staple food and the first cultivated crop in Asia. In India rice has been cultivated since ancient times. This is supported by archaeological evidences and by the numerous references made to rice in ancient Hindu scriptures and literature. Carbonised paddy grains were found in the excavations at Hasthinapur (Uttar Pradesh) at a site dated between 1000 and 750 BC (Choudhry and Ghose, 1953). This is the oldest rice specimen yet known in the world. From the study of Sanskrit and of other different languages in South-Eastern Asia, many investigators have come to the conclusion that rice was known in India before the present era.

De Candolle (1886) and Watt (1892) thought that South India was the place where cultivated rice originated. Vavilov (1926) suggested that India and Burma should be regarded as the centre of origin of cultivated rice.

AREA AND DISTRIBUTION

Rice is the world's second leading food crop after wheat, cultivated over an area of about 162 million hectares with a production of about 755 million tonnes of paddy with productivity of 4661 kg/ha during 2019 (FAOSTAT). It provides about 22% of the world's supply of calories and 17% of the proteins. More than 90 percent area under rice is in Asia. Among the rice growing countries, India has the largest area (43.66 million hectares) followed by China, Bangladesh, Indonesia, Thailand, Vietnam and Myanmar. In respect of production, China ranks first (210 million tonnes of paddy) followed by India (177 million tonnes of paddy), Indonesia and Bangladesh.

In India, rice is grown in almost all the states producing almost 118.9 million tonnes of rice with an average productivity of 2725 kg/ha during 2019-20 (<https://www.indiastatagri.com>). Uttar Pradesh, West Bengal, Odisha, Chhattisgarh and Punjab are leading states in terms of area, whereas West Bengal, Uttar Pradesh and Punjab are the prominent rice producing states. The average productivity of rice is highest in Punjab (3998 kg/ha) followed by Andhra Pradesh, Tamil Nadu and Telangana.

CLASSIFICATION

Rice belongs to genus *Oryza* of Poaceae family (formerly called Gramineae). The genus *Oryza* includes 24 species, of which 22 are wild and two, namely *Oryza sativa* and *Oryza glaberrima*, are cultivated. All the varieties found in Asia, America and Europe belong to *O. sativa* and varieties found in West Africa belong to species *O. glaberrima*.

Oryza sativa is a diploid species having 24 chromosomes. The sativa varieties of the world are commonly grouped into three subspecies, namely *indica*, *japonica* and *javanica*.

1. *Indica*: Rice grown in India belongs to the *indica* subspecies. They are characterised by having leaves slightly pubescent and pale green in colour. Indicas are awnless or possess short and smooth awns. The fruit is caryopsis, elongated, thin, narrow and slightly flattened.
2. *Japonica*: The varieties developed in Japan belong to this subspecies. These varieties are adapted for cultivation in the subcortical and warm temperate regions. *Japonica* varieties mostly have oval and round grains. They may be awned or awnless. Leaves are narrow and dark green in colour.
3. *Javanica*: They are characterised by a stiff straw, long panicle with awned grains, sparse tillering habit, long duration and low sensitivity to difference in day length. These are found mainly in Indonesia.

BOTANICAL DESCRIPTION

The rice plant (*Oryza sativa* L.) is a member of Poaceae family. The common cultivated rice plant is an annual which usually grows to a height of half a

metre to two metres but there are certain varieties that grow much taller (6–9 m). Some deep water rice varieties grow with the gradual rise of the flood water level. Rice plant can be divided into two main parts, namely root system and shoot system.

Root System

When a rice grain germinates in a well drained, upland soil, the sheath (coleorhiza) emerges. If it germinates in submerged low lands, the coleoptile emerges ahead of the coleorhiza. The primary, embryonic root (radicle) comes out through the coleorhiza shortly after it appears. This is followed by two or more secondary roots, all of which develop lateral roots. The embryonic roots later die and are replaced by secondary adventitious roots produced from the underground nodes of the culm (Fig. 1.1).

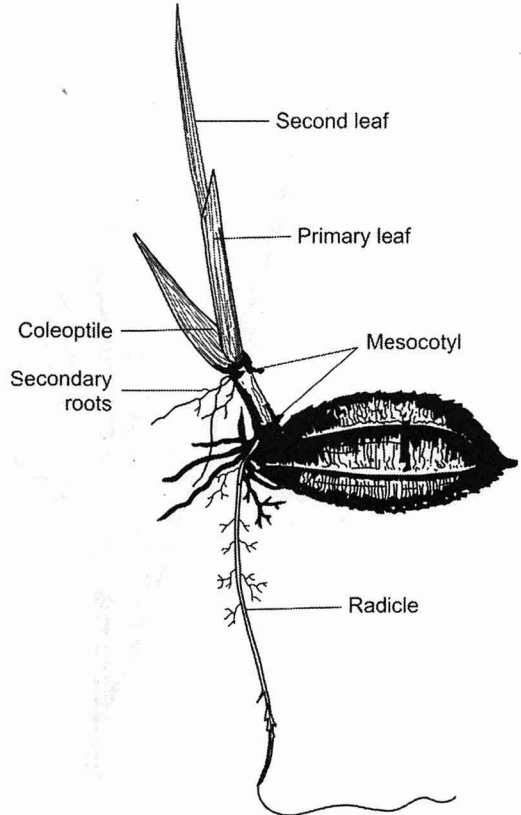


Fig. 1.1: Parts of a rice germinating seedling

Shoot System

Collectively applies to all plant parts visible above the ground level. It is mainly composed of culms, leaves and inflorescence (panicle).

Culm

The culm or stem is made up of a series of nodes and internodes. The rice culms are usually hollow except at the nodes. Each node bears a leaf and a bud. Under favourable conditions buds near ground level grow into tillers. The primary tillers give rise to secondary tillers which give rise to tertiary tillers.

Leaves

The leaves of rice are sessile in nature. They are borne at an angle, on the culm in two ranks along the stem, one at each node. The leaf blade is attached to the node by the leaf sheath. The rice leaf is similar to that of wheat, but is usually distinguished from it by the length of the ligule. In the rice, ligule is very prominent, usually more than one cm. The leaf number is more on a primary tiller than on the secondary and tertiary tillers.

Panicle

The rice inflorescence known as panicle is a group of spikelets borne on the uppermost node of the culm. The primary panicle branch is divided

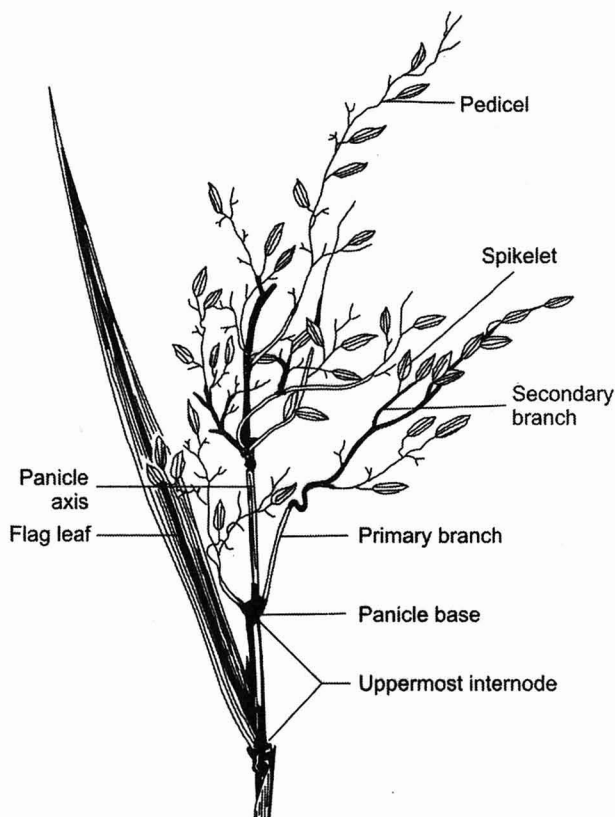


Fig. 1.2: Component parts of a rice panicle

into secondary and sometimes tertiary branches. These bear the spikelets (Fig. 1.2).

Spikelet

The individual spikelet consists of two outer glumes. All the parts found above the 'outer glumes' are collectively called floret. It consists of a hard covering the two sections of which are known as lemma and palea (the glumes) and the complete flower is between them. The lemma and palea together are known as the "hull". The rice flower contains six functioning stamens (male organ) and a pistil (female organ). At the base of the flower are two transparent structures known as 'lodicules' (Fig. 1.3).

Rice is a self-pollinated crop. When rice flower becomes ready to bloom, the lodicules become turgid and push the lemma and palea apart, thus allowing the stamens to emerge outside the open floret. Rupturing of the anthers then leads to the shedding of pollen grains. After the pollen grains are shed on stigma, the lemma and palea close.

Grain (Caryopsis)

Rice grain develops after pollination and fertilisation are completed. The grain is tightly enclosed by the lemma and palea. The dehulled rice grain is known

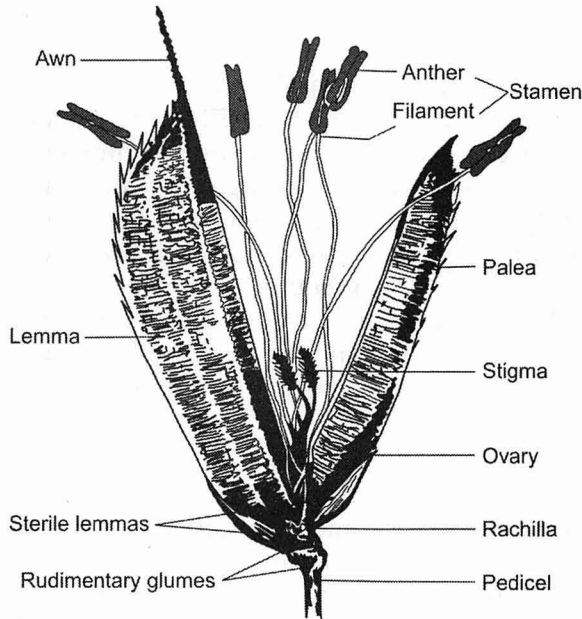


Fig. 1.3: Parts of a rice spikelet

as brown rice as brownish pericarp covers it. The pericarp is the outermost layer which envelops the caryopsis and is removed when rice is milled and polished. The embryo lies at the ventral side of the spikelet next to the lemma. Adjacent to the embryo is a dot-like structure, the hilum. The embryo contains the plumule and radicle. The plumule is enclosed by a sheath known as coleoptile and the radicle by the coleorhiza (Fig. 1.4). The rest of the caryopsis is occupied by the starchy endosperm.

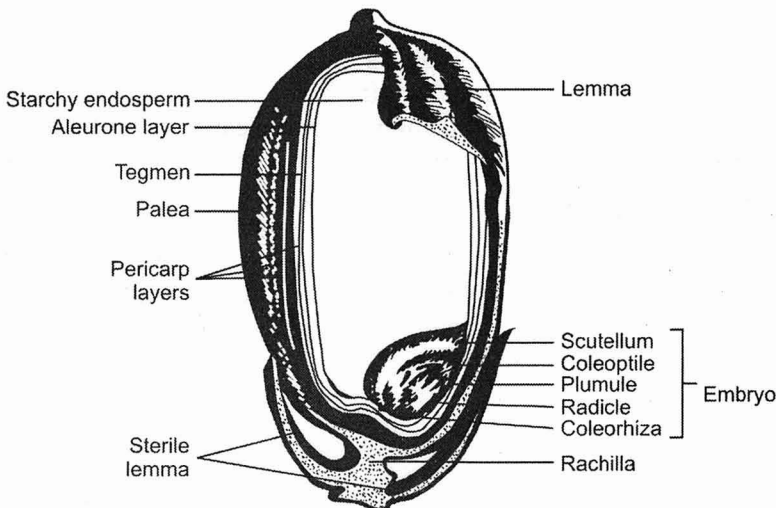


Fig. 1.4: Structure of a rice grain

CLIMATIC REQUIREMENTS

In India rice is grown under widely varying conditions of altitude and climate. Rice cultivation in India extends from 8 to 35°N latitude and from sea level to as high as 3000 m. Rice crop needs a hot and humid climate. It is best suited to regions which have high humidity, prolonged sunshine and assured supply of water. The average temperature required throughout the life period of the crop ranges from 21 to 37°C. At the time of tillering the crop requires a higher temperature than for growth. Temperature requirement for blooming is in the range of 26.5 to 29.5°C. At the time of ripening the temperature should be between 20 and 25°C. Photoperiodically, rice is a short-day plant. However, there are varieties which are non-sensitive to photoperiodic conditions.

Season

Rice-growing seasons vary in different parts of India, depending upon temperature, rainfall and other climatic conditions. In parts of eastern region and Peninsular India, the mean temperatures throughout the year are favourable for rice cultivation and hence two or three crops of rice are taken in a year. In northern and western parts of the country where winter temperatures are fairly low only one crop of rice is taken during *Kharif* season. There are three seasons for growing rice in India as given below:

<i>Crop season</i>	<i>Local name</i>	<i>Sowing time</i>	<i>Harvest time</i>
<i>Kharif</i>	Aus (West Bengal, Bihar)	May–June	Sept.–Oct.
<i>Rabi</i>	Aman or Aghani		
Summer	Dalua (Odisha)	June–July	Nov.–Dec.
Spring	Boro (West Bengal)	Nov.–Dec.	March–April

SOIL

In India rice is grown under so diverse soil conditions that it can be said that there is hardly any type of soil in which it cannot be grown, including alkaline and acidic soils. Soils having good water retention capacity with good amount of clay and organic matter are ideal for rice cultivation. Clay or clay loams are most suited for rice cultivation. Such soils are capable of holding water for long and sustain crop. Rice being a semi-aquatic crop, grows best under submerged conditions. A major part of rice crop in India is grown under 'low land' conditions. Rice plant is able to tolerate a wide range of soil reaction, but it does have a preference for acidic soils. It grows well in soils having a pH range between 5.5 and 6.5. It can be grown on alkali soils also after treating them with gypsum or pyrite.

VARIETIES

Systematic varietal improvement of rice started with the establishment of the Central Rice Research Institute (now National Rice Research Institute), at

Cuttak, Odisha in 1946. There had been a systematic screening of exotic types from the genetic stocks. Besides, for the purpose of direct introduction in the country, many Chinese, Japanese, Taiwanese and Russian types were also tested. The International Rice Research Institute (IRRI) was established in the Philippines in 1960 which helped in evolving dwarf high yielding varieties with the concept of improving the plant type in *indica* rice based on the use of a gene from semi-dwarf Chinese varieties. These high yielding varieties were highlighted during the International Rice Year in 1966 by ICAR through national demonstration trials. This was the beginning of moving towards self-sufficiency in rice production. Further, the ICAR launched the All-India Co-ordinated Rice Improvement Project (AICRIP) in 1965 that helped in co-ordination of interdisciplinary and inter-institutional research on national basis for improving the production, productivity and profitability of rice in India.

Inter-racial hybridization programme between semi-dwarf Taiwanese types/derivatives and *indica* was started during 1965 onwards. India operated its most intensive rice breeding programmes under the AICRIP with the development of Taichung Native-I (TN 1) from the semi-dwarf mutant and achieved remarkable success. Padma and Jaya were the first varieties that emerged from the programme. Subsequently, many semi-dwarf varieties were released by the Central Variety Release Committee and also by the different state agencies. Most of these varieties have got high yield potential. At present, 125 rice research stations representing 28 state agricultural universities are working on all aspects of rice. A good number of varieties combining earliness, resistance to biotic and abiotic stress and grain quality have been developed.

Rice varieties released/notified for cultivation in different ecosystems during last two decades is presented in Tables 1.1 and 1.2. Similarly, varieties released/notified for different states are listed in Table 1.3. The major disease resistance and yield attributing characteristics of prominent varieties are mentioned in Tables 1.4 and 1.5. Recently, efforts have been made to develop bio-fortified varieties of rice as a solution to fight against malnutrition. CR Dhan 310 (protein 10.3%), DRR Dhan 45 (high zinc 22.6 ppm), GN R-4 (high iron 91 ppm, dietary fiber 2.78%, beta-carotene 0.53 ppm), DRR Dhan 48 (high zinc 22 ppm), DRR Dhan 49 (high zinc—25.2 ppm) are some of the bio-fortified varieties developed. The detail of biofortified varieties of rice is mentioned in Table 1.6.

HYBRID RICE

Research programme to develop hybrid rice variety was initiated during 1970 in the country but there was no success in this programme during the subsequent two decades. Rice being self-pollinated crop, in the absence of any cytoplasmic male-sterile (CMS) lines and restorer system, hybrid rice did not click. The CMS lines developed in China were also made available to other rice-growing countries through the IRRI in 1980. Chinese hybrids did not perform well under Indian conditions due to poor quality grains, susceptibility to disease and pests and lower yield than the conventionally bred best varieties. Rice breeders in the IRRI and India developed their own CMS lines using wild

Table 1.1: Released varieties of rice suitable for cultivation in different ecosystems (released/notified during last 20 years)

<i>Ecologies</i>	<i>Name of varieties</i>
Rainfed upland	Anjali (2002), Sadabahar (2004), Virender (2006), CR Dhan 40 (2008), Sahbhagi Dhan (2009), Phalguni (2010), Satyabhama (CR Dhan 100)(2012), CR Dhan 101 (Ankit) (2014), Purna (2017), CR Dhan 102 (Santha Bhima) (2019) Aromatic: Gangavati Ageti (2017)
Rainfed shallow lowland	Reeta (CR Dhan 401) (2010), CR Dhan 701, Sumit (CR Dhan 404) (2012), Poorna Bhog (CR Dhan 902) (2012), CR Dhan 407 (2014), Chaka Akhi (CR Dhan 408) (2014), CR Dhan 800 (2016), CR Dhan 801 (2019), Subhas (CR Dhan 802) (2019), Mahamani (CR Dhan 410) (2019) Flood prone shallow lowlands: Swarna Sub 1 (2009)
Semi-deep water situation	Varsha Dhan (2006), Hanseswari (CR Dhan 70), CR Dhan 501 (2010), Pradhan Dhan (CR Dhan 409) (2016), CR Dhan 506 (2017), CR Dhan 510 (2019), CR Dhan 511 (2019)
Deep water situation	CR Dhan 500 (2011), Jalamani (CR Dhan 503) (2012), Jayanti Dhan (CR Dhan 502) (2012), CR Dhan 505 (2014), Prasant (CR Dhan 507) (2016), CR Dhan 508 (2017)
Medium deep rice	Durga (2000), Sarala (2000)
Irrigated rice	Shatabdi (2000), Hazari Dhan (2004), Abhishek (2006), Naveen (2006), Satya Krishna (CR Dhan 10) (2008) Nua Dhusara (CR Sugandh Dhan 3) (2008), Phalguni (2010), Hue (CR Dhan 301) (2012), Improved Lalat (2012), Improved Tapaswini (2012), CR Dhan 303 (2014), CR Dhan 304 (2014), CR Dhan 305 (2014), CR Dhan 306 (IET 22084) (2014), CR Dhan 307 (2014), Maudamani (2014), CR Dhan 310 (2014), CR Dhan 311 (Mukul) (2016), CR Dhan 309 (2019), CR Dhan 312 (2019) Hybrid: Rajalaxmi (2006), Ajay (2006)
Irrigated Boro rice	Chandrama (2006), Chandan (CR Boro Dhan 2), CR Dhan 601
Aromatic irrigated rice	Irrigated: Geetanjali (2006), CR Dhan 907 (2013), CR Dhan 303 (2013), CR Sugandh Dhan 910 (2016), CR Sugandh Dhan 908 (2017), CR Sugandh Dhan 909 (2017) Shallow lowland: Ketekijoha (2006), Nua kalajeera (2008), Nua Chinikamini (2010),
Coastal saline	Luna Sampad (CR Dhan 402), Luna Suvarna (CR Dhan 403), Luna Sankhi (CR Dhan 405)(2012), Luna Barial (CR Dhan 406) (2012)
Aerobic	Pyari (CR Dhan 200) (2012), CR Dhan 201(2014), CR Dhan 202 (2014), CR Dhan 203 (Sachala) (2014), CR Dhan 204 (2014), CR Dhan 205 (2014), CR Dhan 206 (Gopinath) (2014), CR Dhan 207 (Srimati) (2016), CR Dhan 209 (Priya) (2016), CR Dhan 210 (Sarumina) (2019)

abortive (WA) cytoplasm. With these concerted efforts, a remarkable success was achieved and half a dozen hybrid rice varieties were developed from public and private sectors. The first four hybrid rice varieties were released in the country during 1994. Subsequently, many more hybrids of rice were also released. Some of promising rice hybrids developed in India are listed in Table 1.7.

Table 1.2: Rice varieties released/notified by CVRC during last 20 years for cultivation

2000	Bhoi, CSR-13, CSR-27, Gajapati, Indrabati, Kharavela, Konark, Lalitagiri, Mahanadi, Pooja, Prachi, Ramachandi, Sebati, Surendra, Udayagiri, VL Dhan-81
2001	6201 (PA 103) (Hybrid), CSR 30, Hybrid 6444, Pant Dhan 16, PR-113, PR-114, PR-115, PR-116, Pusa RH-10, Pusa RH-10 (PRR 78), Pusa Sugandh-2, Pusa Sugandh-3, Vasumati, Vivek Dhan 82, Vivek Dhan-62
2002	Anjali, Kaum 57-18-1-1
2003	Bha Lum-2, Dandi, Dhanrasi, GR-8, Lam pnah, RH-204
2004	CSR-23, HPR-1156
2005	BPT-3291 (Sonamasuri), CSR-36 (Naina), DRRH-2 GR-201 (Rashmi), Jarava, JR-503 (Richa), Narendra-8002, Pusa Sugandh-5, Sungandhamati, Suruchi-5401, Warangal Samba (WGL-14)
2006	Dhanu, Dhanya, Ketekijoha, Pant Sankar Dhan-3, Varshadhan, VL Dhan-208, VL Dhan-207, VL Dhan 85
2007	Abhishek, Hybrid-6129, Imprioved Pusa Basmati-1, JKRH-401, Pant Dhan 18, Pant Dhan-19, Rajendra Mahsuri-1, Shusk Samrat, Sugamdhmati, Virender, VL Dhan-86
2008	Akshayadhan, CR Dhan 40, Gontra Bidhan-1, Improved Samba Mahsuri, MTU 1075, Sampada, Thanu, Vardhan
2009	Amal-Mana, DRH-775, Sahyadri-4, Vallabh Basmati-22
2010	DRR-1, DRRH-3, Jagjeevan, KN3, Narendra Usar Dhan-2008 (NDRK-5088), Pusa Basmati-6, Ratnagiri-24, US 312
2011	Chandrama, Chinsurah Rice, CR Dhan 401, CR Dhan 501, CR Dhan 601, IGKVR-1, IGKVR-2, Maniphou 11, SJR-5, Sunbhagi Dhan
2012	Arize Tej (HRI 169), CO 4, CR Dhan 500, CR Dhan 701, Improved Lalat, Improved Tapaswini, Hue, Jalamani, JGL 3828 (Manair Sona), JGL 3844 (Jagtial Samba), Karjat-8, Luna Barial, Luna Sankhi, Mugad Siri-1253, NK 5251, NPH 924, Nua Acharmati, PNP 24, Poorna Bhog, Pyari, Sahyadri-5, Satyabhama, Sumit, US 382, VNR2245
2013	Arize Dhan, CNR-2, CR-1009 SUB-1, DRR Dhan-40, GAR-1, GR-13, KPH-199, KPH-371, Malaviya Basmati Dhan 10, NMH-1242, NP 209, NPG 209, NP 218, NSCH-12 (Misthi), PB-1509, Pratap-1, Pusa-6, Pusa Basmati-1509, Sujala (CNR-2), Sun Vaaman, US 314, VNR 2375 plus
2014	Ankur-7434, ARB 6, Ciherang Sub-1, CR Dhan 201, CR Dhan 202, CR Dhan 300, CR Dhan 303, CR Dhan 304, CR Dhan 305, CR Dhan 407, CR Dhan 505, CR Dhan-201 (Aerobic), (DRR Dhan-44), CR Dhan-300, CR Dhan-303, CSR-43, CSR-43, CSR-43, DRR-44, Gangavati Sona, Gontra Bindhan-3, RNR-15048, SHIATS Dhan-1, Shobhini, US 305, VL Dhan 157, VL Dhan 68
2015	Arize 6444 Gold, Basmati 564, Bina Dhan-10, Bina Dhan-8, Birsa Vikas Dhan-111, Birsa Vikas Dhan-203, Birsa Vikas Dhan-111, Birsa Vikas Dhan-203, Birsa Vikas Sugandha-1, BNKR-1, CO 51, DRR Dhan 41, Indira Aerobic-1, Narendra Sona (NDR 370133), NDR 2101, Nilgiri Khapli (HW 1098), Pushpa, Maniphou 12, Rice CO 51, Sabour Shree, Samba Sub-1, Sukha Dhan-5, TPS 5, Vallabh Bamati 23, Vallabh Basmati-24
2016	Bauna Kalanamak-101, Chandra, MTU-1121(Sri Dhruthi)
2017	DRR Dhan-45, Sampriti
2018	BRRI Dhan 75, CSR 56, IET 24619, Gujarat Anand Rice 14 (GAR 14), Laxmi Plus, CSR60, KHP-13, KKP-5, Pradeep, Pratibha, Swarna Shreya, Rice ADT 51, Tripura Khara 1, Tripura Jala, Tripura Hakuchuk 1, Tripura Aush, Tripura Khara 2, VNR 218
2019	Rice VGD 1, Anjana, Pranahitha, Prathyumna, Chhattisgarh Devbhog, Arize 6129 Gold, BLR-102, BPT 2295, BS-129G, BS-444G, Chhattisgarh Zinc Rice-2,

(Contd.)

	CR Dhan 204, CR Dhan 205, CR Dhan 306, CR Dhan 510, CR Dhan 801, GR-15, GR-15, HKR 128, Malviya Sugandhan Dhan-1304 (HUR-1304), Malviya Sugandh Dhan-1309 (HUR-1309), CR Dhan 510, Ksheera, CR Dhan 801, CR Dhan 802 (Subhas), Bidhan Suruchi, Jammu Basmati 129, Anjana, Pranahitha, Prathyumna, Krishna, Pandu Ranga, Mukul (CR Dhan 311), PAC 801, PAC 837, PAC 8744, PDKV Tilak-2, Ratnagiri-6, Ratnagiri-7, Rice ADT 53, Samvruddh Chhattisgarh Dubraj Mutant-1 Uttar Sona, VNR 2245, VNR 2245, VNR 2355
2020	Arize Tej Gold, CR Dhan 312, Eenotphou CAU-R4, Him Palam Dhan 1 (HPR 2656), Him Palam Dhan 2 (HPR 2880), Mangalphou CAU-R3, MEPH 126, MEPH-129, MEPH-134, MRP 5433, MRP 5626, MP 3030, Pant Dhan 22, Pant Dhan 28, RH-9000 Plus, RYT 13316, PR 127, Sabour Harshit Dhan, Sandhya, Sava 134, Swarna Shakti Dhan, Telangana Vari-1, Tomthinphou, CAU-R2, US 303, US 380, Uttar Lakshmi UBKVR-15

Table 1.3: State-wise major rice varieties released/notified by CVRC during last 20 years

State	Name of varieties
Andhra Pradesh	Cottondora Sannalu (MTU-1010), Deepti (MTU-4870), Maruteru Sannalu (MTU-1006), Somasila (NLR-33358), Srikakulam Sannalu (RGL-2537), Vasundhara (RGL-2538), Vedagiri (NLR-33641), Bharani (NLR 30491), Early Sambha (RNRM-7), Sravani (NLR-33359), Surya (BPT-4358), Swathi (NLR-33057), JGL-1798, JGL-384, MTU-1031(Tholakuri), MTU-1032 (Godavari), Shanthi, Indra (MTV-1061), Pardhiva (NLR-33892), Sree Kurma, Warangal Sannalu (WGL-32100), Taramati (RNR-23064), Amara (MTU-1064), Nellore Mahsuri (NLR-34449), Ramappa (WGL-23985), Srisatya (RGL-1880), Akshaya, Bhavapuri Sannalu, Jagtial Mahsuri (JGL 11470), Karimnagar Samba (JGL 3855), Moti Gold (NP 1024), Sonal (NP 3114), Sugandha Samba (RNR-2465), Vamsadhara (RGL-11414)
Asom	Raneett Sub-1, Bahadur Sub-1
Bihar	Rajendra Kasturi, Rajendra Suwasini, Rajendra Sweta, Rajendra Bhagvati, Sabour Shree, RAU 724-48-33
Chhattisgarh	Bamleshwari, Danteshwari, Indira Dhan-1, Chandrahasini, Indira Sona, Jaldibi, Samleshwari, Karma Mahsuri, IGRKVR-1244, Indira Barani Dhan-1
Gujarat	GR-104, GR-7, GR-9, GR-12, AAUDR-1, GAR-13, NAUR-1, Ratnagiri-4, Gujarat Anand Rice-2
Haryana	HKR-46, Haryana Shankar Dhan-1 (HKRH-1), HKR-47, HKR-127
Himachal Pradesh	HKR-126, Palam Dhan-957, Bhriugu Dhan, HPR 2143, HPR-1068, Varun Dhan, HPR-2656, HPR-2720, HPR-2795, Kasturi
Jammu & Kashmir	Kohsaar, Shalimar Rice-1
Jharkhand	Birsa Vikas Dhan-109, Birsa Vikas Dhan-110, Birsa Mati, Hazari Dhan, Sadabahar, Birsa Dhan-108
Karnataka	Hemavathi (DWR-4107), Karnataka Hill Paddy-5 (KHP-5), Mugad Sugandha-1, Sharavathi, BR-2655, KHP-9, Tunga, CSR22, KHP-10, MGD 101, Ona Siri (MAS 26), Pubm-8, Sharada (MAS 946-1)
Madhya Pradesh	Rashmi(JR-201), JRH-8, JR 767, Swarna Shreya, DRR Dhan 50, improved Chinnor, improved Jeera Shankar, JR-81, JRB-1

(Contd.)

State	Name of varieties
Kerala	Deepthi (WND 111), KAU 87117 (Karuna), KAU 4-4-2 (Harsha), KAUM 20-19-4, KAUM 42-6-3, KAUM 45-20-1, Revathy, KAUM 57-9-1-1 (K-16), Karishma, KAUM 59-29-2-1-2 (GM-1), KAUM 61-6-1-1-2 (GM-9), Kumbham (KTR-3), Makaram (KTR-2), RM-1, Mangala Mansuri, Bhagya, Chingam, Gouri (MO-20), Onam, Matta Triveni (PTB-45), Kairaly (PTB-49), Kanchana (PTB-50), Aathira (PTB-51), Aiswarya (PTB-52), Varsha (PTB-56), VTL-6, Pratiksha (MO 21), PTB-58, VTL-8
Maharashtra	PARAG-401, SAHYADRI, SKL-8, Parbhani Avishkar (PBNR-93-1), Phondaghat-1, PKV Makarand, SKL-8, SYE-2001, Bhogavati, Karjat-5, Phule Radha, Sahyadri-2, Sahyadri-3, Phule Samrudhi, PKV HMT, Karjat-7, PKV Khamang, Karjat-184, Phule Samruddhi (VDN-99-29)
Meghalaya	Bha Lum-1 (RCPL 1-27), Shah Sarang-1 (RCPL 1-87-8), Lum Pnah-1 (RCPL 1-87-4)
Manipur	Pariphou, CAUR-1, Maniphou-10, RC Maniphou-6, RC Maniphou-7
Odisha	CR 683-123, Jagabandhu, Sarala, Vandana, Ajay, Geetanjali, Naveen, Pratikshya, Rajalaxmi, Upahar, Jogesh, Ketekijoha, Sidhanta, CR Boro Dhan-2, CR Dhan-10, CR Dhan-70, CR Sugandh Dhan-3, Jaldi Dhan-6, Manaswini, Nua Kalajeera, Rani Dhan, Swarana-Sub 1, Luna Sampad, Luna Suwarna, Mandakini, Mrunalini, Nua Chinikamini, Phalguni, Reeta, Tejaswani, C R Dhan 800, MTU 1156, Hasanta
Puducherry	PY 6 (Subramania Bharathi), PY-7, KKL (R)-1, TKM 13
Punjab	PR-118, PAU-201, Punjab Basmati-2, PR 121
Tamil Nadu	ADT-44, CO-47 (IET-14298), ADT (R) 45 (IET-15924), TRY (R)-2, TRY 1ADT (R)-46, PMK (R)-3, TMK (R)-12, ADT(R)-48 (AD 95128), ADT (R)-47, CORH-3, RMD (R) 1, TPS (R) 4, Co (R)-48, Anna (R)-4, CO (R)-49, NLR34449, ADT 49, ADT 50, TRY 3, Samba Mahsuri
Telanagana	KNM-118
Tripura	Kali Khasa, Swati
Uttar Pradesh	Narendra Usar-3, PY-6, Malviya Dhan-1 (HUR 2-1), Malviya Dhan-2 (HUR-3022), Barani Deep (NDR 1025-2), Malaviya Sugandh 4-3 (HUR-4-3), Malaviya Sugandh-105 (HUR-105), Narendra Dhan (NDR-9830132), Narendra Dhan 3112, Narendra Jal Pushp, Narendra Lalmati, Narendra Mayank, Narendra Usar Dhan 2008, NDR 2064 NDR 2065, Vallabh Basmati-21, PAC 801 (AH-801), Pant Basmati-2, CR Dhan-310, Shiats Dhan-5, Bauna Kalanamak-102, HUR-917, Pusa Basmati-1718, Rajendra Neelam, SHIATS Dhan 2, SHIATS Dhan 3, CSR 56, CSR 60, CSR-49, CSR-52
Uttarakhand	Vivek Dhan 154, VL Dhan 209, VL Dhan 65
West Bengal	Bhagirathi, Golak, Mahananda, Neeraja, PNR-519, Sashi, Shatabdi, Sudhir, Sunil, PNR-546, Bhudeb, Giri, Jaldi Dhan-13 (PNR-591-18), Ajit, Bheema (MTU-1140), Tarangini, Rajdeep, CR Dhan 800 (Swarna-MAS), Ranjit Sub-1, Bhupesh, Bidhan Suruchi, Chinsurah Nona-2, CR Dhan 311 (Mukul), CR Dhan 511, CR Dhan 801, CR Dhan 802 (Subhar), Manisha, Muktaashree, Uttar Sona

Table 1.4: Characters of important varieties of rice for different ecologies released during last 20 years

<i>Name</i>	<i>Important characters</i>
CR Dhan 309	This variety released in 2019 and recommended for irrigated conditions of Asom, Chhattisgarh and eastern Uttar Pradesh. It is resistant to stem borer (dead heart and white ear head), leaf folder and whorl maggot. The grain of this variety is long slender and average yield is 5.8 t/ha
CR Dhan 801	This variety released in 2019 and shallow lowland (for submergence and drought prone areas) of Andhra Pradesh, Telengana, Odisha, Uttar Pradesh and West Bengal. The variety is moderately resistant to leaf blast, neck blast, bacterial blight, stem borer (both dead heart and white ear heads) and leaf folder. The grain is long slender and average yield is 6.3 t/ha.
CR Dhan 802 (Subhas)	This variety is recommended for shallow lowland (for submergence and drought prone areas) of Bihar and Madhya Pradesh. This variety is resistant to stem borer (both dead heart and white ear heads), leaf folder, plant hopper and case worm while moderately resistant to bacterial blight, sheath rot and rice tungro virus. The duration of the variety is 142 days with average grain yield of 6.5 t/ha.
CR Dhan 510	This variety is recommended for semi-deep ecologies of West Bengal and Odisha. This variety is moderately resistant to blast, bacterial blight, stem borer and leaf folder. The duration of the variety is 160 days with average grain yield of 4.6 t/ha.
CR Dhan 511	This variety is recommended for semi-deep ecologies of West Bengal and Odisha. Variety is moderately resistant to leaf blast, neck blast and bacterial blight diseases, stem borer (both dead heart and white ear heads), white backed plant hopper and leaf folder. The duration of the variety is 160 days with average grain yield of 4.2 t/ha.
CR Dhan 312	This variety is recommended for irrigated conditions of Maharashtra and Chhattisgarh and released in 2019 by CVRC. This variety is moderately resistant to leaf blast, neck blast and rice tungro disease. The duration of the variety varies from 135 to 140 days with average grain yield of 6.4 t/ha.
CR Dhan 102 (Santha Bhima)	This variety is recommended for upland conditions of Odisha and released in 2019. The variety is moderately resistant to leaf blast, rice tungro virus, stem borer, leaf folder and whorl maggot. The duration of the variety varies from 105 to 110 days with average grain yield of 3.9 t/ha.
CR Dhan 210 (Sarumina)	This variety is recommended for aerobic conditions of Odisha and released in 2019. The variety is moderately resistant to leaf blast, neck blast, brown spot, sheath rot, stem borer, leaf folder and green leaf hopper. The duration of the variety varies from 110 to 115 days with average grain yield of 7.8 t/ha.
CR Dhan 410 (Mahamani)	This variety is recommended for rainfed shallow lowland conditions of Odisha and released in 2019. The variety is moderately resistant to stem borer, leaf folder, neck blast, bacterial blight, sheath rot and brown spot. The duration of the variety varies from 160–165 days with average grain yield of 7.0 t/ha.
CR Dhan 506	This variety is recommended for semi-deep ecologies of Asom, Andhra Pradesh and Odisha and released in 2017. The variety is moderately resistant to sheath blight, brown spot and sheath rot. The duration of the variety is 165 days with average grain yield of 4.4 t/ha.

(Contd.)

Name	Important characters
CR Sugandh Dhan 908 (Aromatic)	This variety is aromatic and recommended for irrigated condition of Odisha, West Bengal and UP and released in 2017. This variety is 95 cm tall, moderately resistant to neck blast, bacterial blight, brown spot, stem borer and leaf folder. The duration of variety is 145 days with average yield of 5.0 t/ha.
CR Sugandh Dhan 909 (Aromatic)	This variety is aromatic and recommended for irrigated condition of Asom, Bihar, UP, Maharashtra. This variety is 95 cm tall, moderately resistant to neck blast, bacterial blight, brown spot, stem borer, white back plant hopper and leaf folder. The duration of variety is 140 days with average yield of 5.0 t/ha.
Gangavati Ageti (Aromatic)	This variety is recommended for upland conditions of Karnataka and released in 2017. The variety is moderately resistant to leaf blast, gall midge and leaf folder. The duration of the variety is 85 days with average grain yield of 3.5 t/ha.
Purna	This variety is recommended for upland conditions of Gujarat and released in 2017. The variety is tolerant to drought and moderately resistant to leaf blast, gall midge and leaf folder. The duration of the variety is 90 days with average grain yield of 3.5 t/ha.
CR Dhan 409 (Pradhan Dhan)	This variety is recommended for semi-deep ecologies of Odisha and released in 2016. The height of plant ranges from 130 to 135 cm, moderately resistant to blast, brown spot, bacterial blight and sheath blight and stem borer. The duration of the variety is 160 days with average grain yield of 4.7 t/ha.
CR Dhan 311 (Mukul)	This variety is recommended for irrigated condition of Odisha and released in 2016. This variety is 115 cm tall, tolerant to blast, brown spot, stem borer. The duration of this variety is 120–126 days with high protein (10.1%), zinc (20 ppm) content, with an average yield of 5.5 t/ha.
DRR Dhan 45 (IET 23832)	This variety is a biofortified (high zinc rice variety, semi-dwarf, medium duration) (125 days) variety with non-lodging plant type and long slender grains for irrigated conditions. It is the first high zinc rice variety notified at national level with overall mean zinc content of 22.6 ppm (24.0 ppm in AP, KA and TN) in polished rice. Based on high zinc content and yield performance over 5 t/ha, it is released for the states of Tamil Nadu, Andhra Pradesh and Karnataka. It is developed by Indian Institute of Rice Research, Hyderabad.
CR Dhan 310	This variety is recommended for irrigated conditions and released by CVRC in 2015 for Odisha and Asom. This variety is having 110 cm height with high protein content (10.5%) in grains. The duration of this variety is 125 days with an average yield of 5.0 t/ha.
CR Dhan 303	This variety is recommended for irrigated condition and released in 2014 for cultivation in Madhya Pradesh, UP and Odisha. This variety is resistant to leaf folder and moderate resistant to blast, neck blast, bacterial leaf blight, sheath rot and stem borer. The duration of this variety is 125 days with an average yield of 5.0 t/ha.
CR Dhan 505	This variety is recommended for deep ecologies of Odisha and Asom released in 2014. This variety is submergence tolerance and elongation ability, moderately resistant to blast, neck blast, sheath rot, sheath blight and rice tungro virus, stem borer (both dead heart and white ear heads), leaf folder. The duration of this variety is 162 days with an average yield of 4.5 t/ha.
CR Dhan 601	This variety is recommended for boro cultivation in Odisha, West Bengal and Asom and released in 2014. The height of plant is 90 cm,

(Contd.)

Name	Important characters
CR Dhan 907 (Aromatic)	tolerant to cold, resistant to blast, rice Tungro virus and moderately resistant to brown spot, sheath rot. The duration of the variety is 135 days (kharif) and 160 days (rabi) with average grain yield of 5.6 t/ha. This is aromatic variety recommended for irrigated conditions (late) of Chhattisgarh, Odisha, Andhra Pradesh and Gujarat released in 2013. This variety is semi-dwarf and resistant to neck blast and moderately resistant to gall midge. The duration of variety is 150 days with average yield of 4.0–4.5 t/ha.
CR Dhan 300	This variety is recommended for irrigated condition and released in 2013 for cultivation in Maharashtra, Gujarat, Odisha and Bihar. This variety is resistant to leaf folder and moderate resistant to blast, neck blast, bacterial leaf blight, sheath rot and stem borer. The duration of this variety is 140 days with an average yield of 5.0–5.5 t/ha.
CR Dhan 701	This variety is recommended for shallow lowlands of UP, Bihar, Gujarat and Odisha. This variety is moderately resistant to sheath blight and brown spot with duration of 142 days with average grain yield of 6.0 t/ha.
Lalat (improved)	This variety is recommended for irrigated condition of Odisha and released in 2012. This variety is resistant to bacterial leaf blight, gall midge and moderately resistant to stem borer. The duration of this variety is 130 days with an average yield of 4.5 to 5.0 t/ha.
Tapaswini (improved)	This variety is recommended for irrigated condition of Odisha and released in 2012. This variety is resistant to bacterial leaf blight, brown plant hopper, white back plant hopper and moderately resistant to stem borer. The duration of this variety is 130 days with an average yield of 4.5 to 5.0 t/ha.
Luna Barial (CR Dhan 406)	This variety is suitable for coastal saline conditions of Odisha and released in 2012. The plant height is 120 cm and resistant to blast and sheath blight and tolerant to leaf folder. The duration of this variety is 150 days with an average yield of 4.1 t/ha.
Luna Sankhi (CR Dhan 405)	This variety is suitable for coastal saline conditions of Odisha and released in 2012. The variety is resistant to blast and sheath blight. The duration of this variety is 110 days with an average yield of 4.6 t/ha.
CR Dhan 501	This variety is recommended for semi-deep ecologies of UP and Asom and released in 2010. This variety is medium in height (135 cm) resistant to blast, with duration of 152 days with average grain yield of 3.4 t/ha.
Phalguni	This variety is suitable both for bunded upland and irrigated conditions of Odisha and released in 2010. The variety is resistant to leaf blast and moderately resistance to brown spot, sheath rot, stem borer and green leaf hopper. The duration of variety is 117 days and give grain yield of 4.0–4.5 t/ha during <i>Kharif</i> and 5.5–6.0 t/ha during <i>Rabi</i> season.
Luna Suvarna (CR Dhan 403)	This variety is suitable for coastal saline conditions of Odisha and released in 2010. The plant height is 135 cm and resistant to blast and tolerant to stem borer and brown plant hopper. The duration of this variety is 150 days with an average yield of 3.5–4.0 t/ha.
Luna Sampad (CR Dhan 402)	This variety is suitable for coastal saline conditions of Odisha and released in 2010. The plant height is 135 cm and resistant to blast and tolerant to stem borer and brown plant hopper. The duration of this variety is 140 days with an average yield of 3.6–4.2 t/ha.

(Contd.)

Name	Important characters
Swarna Sub1	This variety is recommended for flood prone shallow lowlands conditions of Odisha and released in 2009. The variety is tolerant to complete submergence between 15–17 days. The duration of this variety is 145 days with an average yield of 5.2 t/ha.
Sahbhagi Dhan	This variety is recommended for rainfed uplands and CVRC released it for Odisha and Jharkhand in 2009. The variety is drought tolerant and resistant to leaf blast and moderately resistance to brown spot, sheath rot, stem borer and leaf folder. The duration of this variety is 105 days with an average yield of 3.5–4.0 t/ha.
CR Dhan 40	This variety is recommended for banded upland conditions of Jharkhand and Maharashtra. The variety is drought tolerant and moderately resistance to bacterial blight, sheath blight, white back plant hopper, stem borer and resistant to gundhi bug. The duration of this variety is 110 days with an average yield of 3–3.5 t/ha.
Nua Kalajeera (Aromatic)	This variety is recommended for shallow lowlands of Odhisa. This variety is aromatic, photosensitive and having black husk and moderately resistant to bacterial blight and sheath rot. The duration of variety is 150 days with average yield of 2.8 t/ha.
Nua Dhusara (CR Sugandh Dhan 3)	This variety is recommended for shallow lowlands of Odhisa and released in 2008. This variety is aromatic, photosensitive, resistant to neck blight, sheath rot and rice Tungro virus. The duration of variety is 150 days with average yield of 3.0 t/ha.
Chandan (CR Boro Dhan 2)	This variety is recommended for irrigated conditions of Asom and Odisha (125 days), released in 2008 and also suitable for Boro rice (145 days). This variety is moderately resistant to stem borer, brown plant hopper, bacterial blight, sheath blight with average grain yield of 6.1 t/ha.
Hanseswari (CR Dhan 70)	This variety is recommended for semi-deep ecologies of West Bengal and Odisha and released in 2008. This variety is moderately resistant to blast, with duration of 160 days with average grain yield of 3.0 t/ha.
Varshadhan	This variety is recommended for semi-deep ecologies of Odisha and West Bengal and released in 2006. The height of plant is 150 cm having stiff straw for water logging conditions, moderately resistant to neck blast and bacterial blight and sheath rot. The duration of the variety is 160 days with average grain yield of 3.5–4.0 t/ha.
Chandrama	This variety is recommended for irrigated conditions of Asom (130days), released in 2006 and also well suited for Boro rice (170 days). The variety is resistant to blast, bacterial leaf blight, leaf blast, rice tungro virus, stem borer, leaf folder and whorl maggot.
Geetanjali (Aromatic)	This is aromatic variety recommended for irrigated conditions of Odhisa. This variety is semi-dwarf and resistant to neck blast and moderately resistant to gall midge. The duration of variety is 130 days with average yield of 4.5 t/ha.
Ketekijoha (Aromatic)	This variety is recommended for shallow lowlands of Odhisa. This variety is moderately resistant to bacterial blight, sheath blight, stem borer and resistant to gall midge. The duration of variety is 145 days with average yield of 3.5 t/ha.
Rajalaxmi (Hybrid)	This variety is recommended for irrigated conditions of Odhisa and Asom. This variety is semi-dwarf and resistant to neck blast and moderately resistant to gall midge. The duration of variety is 135 days with average yield of 5.85 t/ha.
Abhishek	This variety is recommended for irrigated conditions of Bihar, Jharkhand, Asom and UP and released by CVRC in 2006. This

(Contd.)

Name	Important characters
Hazari Dhan	variety is semi-dwarf (95–110 cm) resistant to blast and moderately resistant to brown spot and gall midge. The duration of the variety varies from 125 days with average grain yield of 4.5–5.0 t/ha.
Sadabhar	This variety is recommended for irrigated conditions of Jharkhand and released in 2004. This variety is resistant to blast and moderately resistant to bacterial blight. The duration of the variety varies from 120 days with average grain yield of 3.7 t/ha.
Shatabdi	This variety is recommended for upland conditions of Jharkhand and released in 2004. This variety is moderately resistant to stem borer with average grain yield of 3.3 t/ha.
Anjali	This variety is recommended for irrigated conditions of West Bengal. The variety is suitable for dry season with average yield of 3.7 t/ha.
Sarala	This variety is recommended for upland conditions of UP, Bihar, Jharkhand, Asom and Tripura. The variety is moderately resistance to bacterial blight, sheath blight, stem borer, white black plant hopper and gall midge. The duration of this variety is 95 days with an average yield of is 3 t/ha.
Durga	This variety is recommended for medium deep water conditions of Odisha and released in 2000. The variety is non-lodging and photosensitive. The duration of the variety is 150 days with average grain yield of 4.75 t/ha.
	This variety is recommended for medium deep water conditions of Odisha and released in 2000. Variety is suitable for late planting with average yield of 4.3 t/ha.

Table 1.5: Characteristics of major rice varieties of irrigated plains of northern India (during last 20 years)

Name	Important characters
PR 129 (2020)	PR 129 is an improved version of PAU 201. It possesses long slender clear translucent grains. The average plant height of the variety is 105 cm and matures in about 138 days after seeding. The average paddy yield is 7.5 t/ha and it is resistant to all the ten presently prevalent pathotypes of bacterial blight pathogen in the Punjab state.
PR 128 (2020)	It is also an improved version of PAU 201. It possesses long slender clear translucent grains. Its average plant height is 110 cm and matures in about 141 days after seeding with average paddy yield is 7.62 t/ha. It is resistant to all the ten presently prevalent pathotypes of bacterial blight pathogen in Punjab.
PR 127 (2018)	It is a medium maturing rice variety with an average height of 104 cm. It matures in about 137 days after seeding. It possesses long slender, clear translucent grains with high total and head rice recoveries. It is resistant to all the ten presently prevalent pathotypes of bacterial blight pathogen in Punjab. Its' average paddy yield is 7.5 t/ha. This variety should not be grown in alkali soils and under brakish water.
PR 126 (2017)	It is an early maturing rice variety. Its average plant height is 102 cm and matures in about 123 days after seeding. It possesses long slender, clear translucent grains. It is resistant to seven of the ten presently prevalent pathotypes of bacterial blight pathogen in Punjab. Its' average paddy yield is 7.5 t/ha.
PR 124 (2015)	The average plant height of PR 124 is 107 cm and matures in about 135 days after seeding. It possesses long slender, clear translucent

(Contd.)

Name	Important characters
	grains. It is resistant to all the ten presently prevalent pathotypes of bacterial blight pathogen in Punjab. This variety is susceptible to brown leaf spot. For its management use recommended fungicides. Its average paddy yield is 7.62 t/ha.
PR 123 (2014)	The average plant height is 105 cm and matures in about 143 days after seeding. It possesses extra long slender, clear translucent grains with excellent cooking and eating quality characteristics. It is resistant to all the ten presently prevalent pathotypes of bacterial blight pathogen in Punjab. Its average paddy yield is 7.25 t/ha.
PR 122 (2013)	The average plant height of PR 122 is 108 cm and matures in 147 days after seeding with average yield of 7.87 t/ha. It possesses long slender translucent grains. It is resistant to all the ten presently prevalent pathotypes of bacterial blight pathogen in Punjab.
PR 121 (2013)	It is a short statured, stiff strawed lodging tolerant variety with dark green and erect leaves. It attains height of about 98 cm and matures in 140 days after seeding with average yield of 7.62 t/ha. The grains are long slender, translucent with good cooking quality.
PR 114 (2000)	It has narrow, dark green erect leaves. It attains an average height of about 102 cm and matures in about 145 days after seeding with average yield of 6.87 t/ha. It possesses extra long, clear translucent grains.
HKR 127	The average plant height is 121 cm and matures in about 140 days after seeding. It possesses long slender, translucent grains. The average yield is 7.0 t/ha with potential yield of 10.0 t/ha.
HKR 126	The height is 110 cm and matures in about 140 days after seeding. It possesses long slender, translucent grains. It is resistance to white backed plant hopper and stem rot and can tolerate water stress to some extent. The average yield is 7.75 t/ha.
HKR 120	The height is 105 cm and matures in about 146 days and lodging resistance. It possesses long slender, translucent grains. The average yield is 6.25 t/ha.
HKR 47 (2020)	It is a mid-early maturing variety. It takes about 134 days to mature after seeding with average plant height is 117 cm. It possesses long slender, clear translucent grains. It is susceptible to bacterial blight and is prone to lodging. Its average paddy yield is 7.37 t/ha.
HKR 46	It is a mid-early maturing variety. It takes about 135 days to mature after seeding with average plant height is 104 cm. It possesses long slender, clear translucent grains. The average yield is 6.25 t/ha.
HKR 48	It is an early maturing variety. It takes about 118 days to mature after seeding with average plant height is 118 cm. It possesses long slender, clear translucent grains. The average yield is 6.0 t/ha.
Govind	It is early maturing variety resistance to lodging. It takes about 118 days to mature after seeding with average plant height is 93 cm. The average yield is 5.25 t/ha.

CROPPING SYSTEMS

In North India where irrigation facilities exist, a number of cropping systems of crops involving rice are feasible. After harvest of rice, crops like potato, berseem, toria, etc. can be sown and will fit very well in intensive crop rotations. In rainfed areas too, where the soils are well drained and have good moisture retention capacity, legume crops like chickpea, lentil could be grown successfully after the harvest of rice, which mature on the residual moisture in the soil. Some of the cropping systems are given as follows:

Table 1.6: Biofortified varieties of rice

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
CR Dhan 310	Rich in protein (10.3%) in polished grains in comparison to 7.0–8.0% in popular varieties	Suitable for irrigated mid-early conditions in <i>khariif</i> . Odisha, Madhya Pradesh and Uttar Pradesh	45.0	125	ICAR–National Rice Research Institute, Cuttack
DRR Dhan 45	Rich in zinc (22.6 ppm) in polished grains in comparison to 12.0–16.0 ppm in popular varieties	Suitable for irrigated conditions in <i>khariif</i> . Karnataka, Tamil Nadu, Andhra Pradesh and Telangana	50.0	130	ICAR–Indian Institute of Rice Research, Hyderabad
DRR Dhan 48	Rich in zinc (24.0 ppm) in polished grains in comparison to 12.0–16.0 ppm in popular varieties	Suitable for irrigated conditions in <i>khariif</i> . Andhra Pradesh, Telangana, Tamil Nadu, Karnataka, and Kerala	52.0	138	ICAR–Indian Institute of Rice Research, Hyderabad
DRR Dhan 49	Rich in zinc (25.2 ppm) in polished grains in comparison to 12.0–16.0 ppm in popular varieties	Suitable for irrigated conditions in <i>khariif</i> and <i>rabi</i> . Gujarat, Maharashtra and Kerala	50.0	130	ICAR–Indian Institute of Rice Research, Hyderabad
Zinco Rice MS	Rich in zinc (27.4 ppm) in polished grains in comparison to 12.0–16.0 ppm in popular varieties	Suitable for early and medium sowings under rainfed and irrigated conditions in <i>khariif</i> . Chhattisgarh, West Bengal and Odisha	58.0	135	Indira Gandhi Krishi Vishwavidyalaya, Raipur
CR Dhan 311 (Mukul)	Rich in protein (10.1%) and zinc (20.1 ppm) in polished grains in comparison to (7.0–8.0%) protein and 12.0–16.0 ppm zinc in popular varieties	Suitable for rainfed shallow lowland and medium land in <i>khariif</i> . Odisha	46.2	124	ICAR–National Rice Research Institute, Cuttack
CR Dhan 315	Rich in zinc (24.9 ppm) in polished grains in comparison to 12.0–16.0 ppm zinc in popular varieties	Suitable for irrigated conditions in <i>khariif</i> . Maharashtra, Gujarat	50.0	130	ICAR–National Rice Research Institute, Cuttack

Source: Yadava et al, 2020.

Table 1.7: Promising rice hybrids for cultivation in different states

<i>Name of hybrid</i>	<i>Duration (days)</i>	<i>Yield (q/ha)</i>	<i>Released for states</i>
Pant Sankar Dhan 1	115–120	68	Uttar Pradesh
Narendra Sankar Dhan 2	125–130	61.5	Uttar Pradesh
PHB 71	130–135	78.6	Haryana, UP
PRH 122	95–100	56.4	Uttarakhand, Punjab, Haryana, UP, Bihar, Odisha
Hybrid 6129	85–90	65.8	Punjab, Tamil Nadu, Puducherry
JRH 4	87–90	75	Madhya Pradesh
JRH 5	87–90	75	Madhya Pradesh
JKRH 401	135–140	62	West Bengal, Bihar, Odisha
Indra Sona	125–128	68	Chhattisgarh
HKRH 1	135–140	94	Haryana
Sahyadri 2	115–118	65	Maharashtra
Sahyadri 3	123–126	75	Maharashtra
Pusa RH 10	120–125	44	Haryana, Punjab, Delhi, Western UP
Rajlakshmi	130–135	57	Odisha (irrigated area only)
DRRH 1	125–130	70	Haryana, Uttarakhand, Tamil Nadu, Andhra Pradesh
DRRH 2	112–116	54	Haryana, Uttarakhand, West Bengal, Tamil Nadu
APHR 1	130–135	70	Telangana, Andhra Pradesh, coastal Tamil Nadu
APHR 2	130–135	75	Telangana, Andhra Pradesh, coastal Tamil Nadu
RH 204	120–128	69	Karnataka, Rajasthan, Uttarakhand
Suruchi 5401	130–135	59	Haryana, Karnataka, Andhra Pradesh, Maharashtra
Pant Sankar Dhan 3	125–130	61	Uttarakhand
Narendra Usar Sankar Dhan 3	130–135	51	Saline and alkaline areas of UP
Ajay (CRHR7)	130–135	60	Irrigated area of Odisha
Pro-Agro	115–120	60	Haryana, Punjab, Uttar Pradesh, Bihar
Mahyco 504	120–125	65	Haryana, Punjab, Uttar Pradesh, West Bengal
JK 6004	120–125	65	Haryana, Punjab, Jammu, Uttar Pradesh

(A) Irrigated Areas

1. Rice—wheat
2. Rice—potato—urad (black gram)
3. Rice—toria—wheat
4. Rice—wheat—moong (green gram)
5. Rice—potato—moong (green gram)
6. Rice—pea (for pods)—moong (green gram)
7. Rice—wheat—jute
8. Rice—field peas—sugarcane.

(B) Un-irrigated Areas

1. Rice—chickpea
2. Rice—lentil
3. Rice—field pea

In case of intensive crop rotations where there are more than two crops in a year, a paddy variety of early duration should be selected.

In South India, where the winter temperature is not so low, double cropping of rice is practised. In eastern India, in low-lying areas a crop of jute is grown followed by rice. Some of the cropping systems are as follows:

1. Rice—rice—wheat
2. Jute—rice—wheat
3. Rice—maize—jute
4. Rice—potato—jute

CULTIVATION

In India rice is grown mainly on two types of soils, i.e. uplands and lowlands. The system of rice cultivation in a region depends largely on factors such as situation of the land, type of soil, irrigation resources, availability of labourers, intensity and distribution of rainfall, etc. The following are the principal systems of rice cultivation.

1. Dry or semi-dry upland cultivation
 - (a) Broadcasting the seed
 - (b) Sowing the seed behind the plough or drilling
2. Wet or lowland cultivation
 - (a) Transplanting in puddled soils
 - (b) Broadcasting sprouted seeds in puddled soils

DRY OR SEMI-DRY RAINFED UPLAND CULTIVATION (DIRECT SEEDING)

A vast tract of rice in Uttar Pradesh, Bihar, Odisha, parts of Tamil Nadu and Andhra Pradesh is under rainfed upland situation. There is a lack of irrigation facilities and the crop depends entirely on rains. In such areas farmers generally grow short duration (up to 100 days) indigenous varieties with little inputs and harvest only 10–12 quintals paddy/ha. By using improved dwarf varieties and new technology the farmers can take higher yields. Following are some important points for cultivation:

Selection of Varieties

Short duration varieties of 100–105 days duration should be selected.

Field Preparation

After harvesting the *Rabi* crops in April–May, the fields should be ploughed with soil turning plough. This is helpful in weed eradication as well as improvement in the water holding capacity of the soil. The field should be

prepared and bunds should be made around the field just after the first shower of monsoon. This will check loss of rainwater by runoff.

Seed and Sowing

Seed treatment: Before sowing treat the seed @ 10 kg seed with 5 g emisan, 1 g streptocycline or 2.5 g agromycine 100 or pausamycine in 10 L of water for 24 hours.

Broadcasting

When the field is in the right condition, broadcast the seeds. Mix seeds in the soil with the help of local plough or disc harrow. Use about 100 kg seed/ha.

Sowing Seed behind the Plough or Drilling

Drill the seed with seed drill or behind the plough with the help of funnel in rows after applying fertiliser. The row to row distance should be 20 cm. About 60 kg seed is sufficient for one hectare.

Fertiliser Application

A good crop of upland rice may be taken by applying 60 kg nitrogen, 30 kg phosphorus and 30 kg potash/ha. Total quantity of phosphorus and potash and 25% of the total nitrogen should be applied in the soil at the time of land preparation. Ferti-seed drill may also be used for sowing of seed and placement of fertiliser. After 35–40 days of sowing or at tillering stage, top dress 50% of the total nitrogen. The remaining 25% nitrogen should be top dressed at panicle initiation stage.

Weeding and Hoeing

In upland rice cultivation, weeds are a major problem. Hence effective weed control is very important from the very beginning Benthicarb (Saturn) @ 2 kg active ingredient /ha should be applied six to seven days after seeding of rice. It should be followed by one manual weeding 40–45 days after sowing.

Disease and Pest Control

Disease and pest control measures for dry or semi-dry upland rice are similar to that for transplanted rice which is mentioned in the end of this chapter.

Direct Seeded Rice (DSR) for Irrigated Plains

The popular/conventional paddy cultivation is through transplanting, which involves nursery raising of seedlings, puddling of field with stagnated water and transplanting of seedlings in the main field. Puddling destroys soil aggregates, reduces permeability in subsurface layers and forms hard pans at shallow depths. Thus, it not only affects the physical properties of soil but also affects the succeeding non-rice crop. Thus, cultivating puddled rice in unconventional areas using ground water can have even more adverse effects. Nevertheless, labour shortage and increasing wages are adding to the cost of



Fig. 1.5: Laser levelling for field preparation for DSR (see Colour Plate 1)



Fig. 1.6: Direct sowing of rice in laser levelled field (see Colour Plate 1)



Fig. 1.7: 50 days paddy crop raised under DSR (see Colour Plate 1)



Fig. 1.8: Paddy crop in panicle stage under DSR (see Colour Plate 1)

cultivation. Apart from labour scarcity, the drudgery involved for transplanting is also of serious concern, especially for farm women.

The technology of direct seeded rice (DSR) has been developed as an alternative to conventional method of transplanting. Though the technology is knowledge driven but saving in labour, water and energy are the major drivers of DSR. Scientific evidences revealed that farmers can achieve same yield with DSR at par with the puddle transplanted rice (PTR). As per estimate, around 23% of global rice area is under DSR as compared to that of about 21% in Asia. Moreover, area under direct-seeded rice (DSR), both wet and dry DSR in India is around 12 million hectares which constitutes about 28%. DSR overcomes the problem of seasonality of labour requirement for nursery raising and transplanting by spreading out the labour demand over a longer period. It also helps in making full use of the family labour and reducing dependence on hired labour. It also facilitates timely sowing of paddy as well as the succeeding crops, particularly wheat crop which is sensitive to delayed planting. It is because the DSR, particularly the coarse varieties, matures almost one week earlier compared to the transplanted paddy. Nevertheless, wheat grown after DSR has better productivity due to improved soil structure, root growth, crop growth and yield. The comparison of PTR vs DSR is mentioned below:

Components	Puddled transplanted rice (PTR)	Direct seeded rice (DSR)
Irrigation water	120–150 cm water is required	18–27% saving in irrigation water
Puddling	Involves cost of Rs. 2500/ha on machines, fuel, etc. for puddling, destroys soil structure due to puddling, more wear and tear of machines	Absence of puddling saves cost, energy, water, soil structure
Labour requirement	High in manually transplanted (Rs.5500/ha)	No labour is required for transplanting
Nursery cost	Rs.1500/ha minimum	No such cost involved
Weed flora	Specialized due to submergence	Diverse, including volunteer plants
Weed management	Low cost Rs. 500/ha	High cost Rs. 2500/ha
Iron deficiency	Only when fields are exposed to aerobic conditions	More common in lighter soils
System productivity	Lower	Higher

The direct seeding of rice (DSR) has evolved a method to address all above mentioned issues in the vast track of irrigated plains of Punjab and Haryana. It has been recommended for medium to heavy textured soils. Its cultivation is not successful in light textured soil due to severe iron deficiency. Laser leveling is prerequisite for DSR which improves water use efficiency and ensure better germination. Suitable short and medium duration varieties should be sown during first fortnight of June using 20–25 kg seed per hectare. Direct seeded rice can be sown by two methods—namely dry sowing (Dry-DSR) and wet sowing (Wet-DSR).

Direct seeding in dry fields: Treat the dry seed with 3 g Sprint 75 WS (mencozeb + carbendazim) per kg seed. Seed should be placed 2–3 cm deep in rows spaced at 20 cm. Dry seed of rice is sown in a dry field and irrigation is applied immediately after sowing.

Direct seeding in wet fields: After laser leveling, field is irrigated. When field comes to tar-wattar condition (sufficiently high but workable soil moisture), prepare field with shallow cultivation followed by planking twice and sow immediately. Field preparation and sowing should be done in evening hours.

DSR helps to avoid repeated puddling and thus prevents soil degradation and hard-pan formation. It also facilitates timely establishment of paddy field and harvesting of paddy about one week earlier, thereby allowing timely sowing of the next crop which enhance the system productivity. The prospects and challenges in promotion of DSR in vast tract of north India is mentioned in Fig. 1.9:

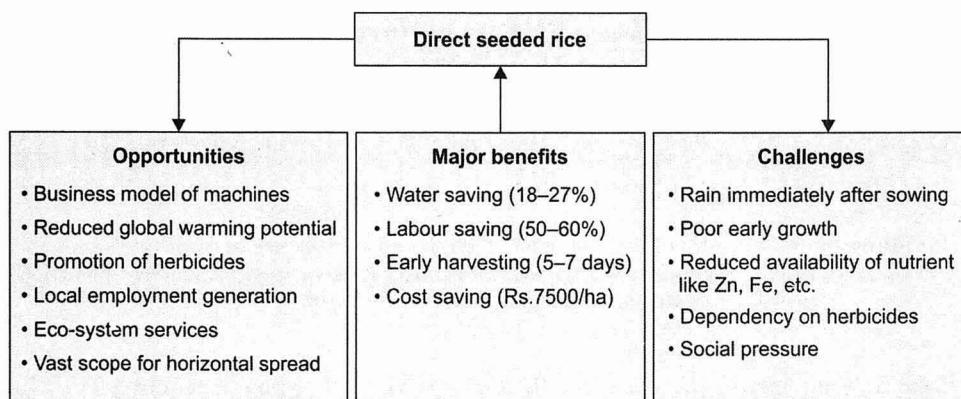


Fig. 1.9: Prospects and challenges in promotion of DSR

Weed Control for Direct Seeded Rice (DSR): Weed management is one of the most critical factors for the successful cultivation of direct seeded rice (DSR). For controlling weeds, spray 2.5 litres per hectare of pendimethalin 30EC (Stomp/Bunker) in 500 litres of water in moist soil within two days of sowing. It should be followed by 250 ml/ha of bispyribac 10SC (Nominee Gold/Wash out/Macho/Taarak) if the crop is infested with *swank* and paddy *mothas* or 40 g/ha of azimsulfuron 50 DF (Segment) or 20 g/ha metsulfuron methyl + chlorimuron ethyl (Almix 20 WP) if the crop is infested with paddy *mothas* and broadleaf weeds at 20–25 days of sowing in 350–400 litres of water. The left over weeds may be uprooted by hand pulling/weeding.

COVID scenario and cloud over paddy cultivation: During lockdown due to COVID-19, serious concerns were mounted on labour availability which may jeopardize agricultural production and consequently national food security in bread basket of the country. During Kharif-2020, Punjab exhibited

unprecedented coverage under DSR in 20 percent of total area under paddy (almost 6 lakh ha). This is not less than a silent revolution occurred during COVID pandemic which translated into saving of around Rs 600 crores in monetary term besides 30 percent saving in ground water and associated pumping costs. Extensive efforts are needed to popularize DSR so that saving of natural resources (soil, water) can pave way towards sustainability of rice cultivation in the scenario of labour scarcity.

WET OR LOWLAND CULTIVATION

This system of rice culture is practised where there is an assured and adequate supply of water. In this system, sprouted seeds may be directly sown in puddled field or the crop may be transplanted with seedlings raised in a nursery. The details of both the systems are given as follows.

Transplanting Method

Much of the success in this system depends on seedlings. If nursery is good and the seedlings are robust and healthy, then one can hopefully look for a bumper crop.

Raising Seedlings in Nursery

Select a fertile, well-drained upland field near the source of irrigation. For transplanting one hectare area about 500 sq m area is sufficient for nursery raising. In case of late sowing area of nursery should be increased to 750–1000 sq m. Seed should always be true to the variety, healthy, viable, clean and of high germination percentage (80% or more). All these points are automatically taken care of in a seed certified by an authorised agency.

In case of bold grain varieties, about 40 to 45 kg seed would be required to raise seedlings enough for one hectare, whereas for fine grain varieties 30 to 35 kg seed is enough.

Rice seeds required to raise seedlings should be soaked in water and pregerminated. Seeds that are germinated before sowing will start to grow quickly in the field or seedbed. Pre-germination consists of soaking and incubating the seeds. Put seed in some container. Then pour water slowly in the container until it is about 10 cm above the seed. Stir the seeds for a minute or so. Unfilled seeds would begin to float. Remove these seeds by draining water. Repeat the process till all unfilled seeds are removed. Thereafter soak the seeds in freshwater and keep at room temperature (27°C or higher) for 24 hours. After 24 hours wash the seeds thoroughly with freshwater. Thereafter place the seeds in a clean and moist bag, fold the bag tightly and keep it in a shady place. Stir the seeds every 12 hours for better air circulation and sprinkle water over seeds while stirring. Incubation period of 24 to 36 hours is required for wet and dry bed methods and 36 to 48 hours for 'Dapog' method of seedling raising.

METHODS OF RAISING SEEDLINGS

There are three major methods, i.e. wet bed, dry bed and dapog, for raising rice seedlings.

Wet Bed Method

Wet nurseries are preferred under irrigated condition. The soil is puddled by two to three runs of puddler or three to four ploughings with local plough. After one or two days of puddling, divide the nursery area into narrow beds of 1.25 m width and of any convenient length depending upon the slope. This facilitates sowing, weeding, spraying of chemicals and irrigation operations. Construct the drainage channels 30 cm wide in between the seed beds. Apply 225 g urea and 500 g single super phosphate/10 sq m. Uniformly broadcast about two to three handfuls of seed on a square metre of seedbed. Keep the seedbeds saturated with water for first five days and then increase gradually the level of water up to 5 cm as the seedlings grow. Drain the excess water in periods of heavy rains during the first week of sowing. Adopt suitable disease and pest control measures. An application of 50 g of urea/sq m may be made by top dressing in case of nitrogen deficiency symptoms. In zinc deficient soils, give two sprays of zinc sulphate (5 kg zinc sulphate + 2.5 kg calcium hydroxide mixed in 1000 L of water for one hectare), one 10 days after sowing and another 20 days after sowing. In case of iron deficiency 0.5%, ferrous sulphate solution should be sprayed. Seedlings would be ready for transplanting at an age of 20–25 days.

Dry Bed Method

This method is practised in areas where water is not sufficient to grow seedlings in wet nurseries. Plough the field three to four times till the soil is thoroughly pulverised. Prepare beds of the same size as in wet nurseries but 15 cm high with channels (30 cm wide) between them. Sow the seed in rows 10 cm apart in dry or moist condition of soil. Use the same seed rate and fertiliser as in wet nurseries. The sown seeds should be covered immediately with a layer of soil. Special care should be taken for water management in these beds. Allow the water to run in channels first and then raise the level of water slowly to saturate the soil of beds. Do not flood water in beds. Keep the seed bed saturated with water although. Maintain a thin film of water if possible after 5 days of sowing. Follow all the operations as described for wet nurseries.

Dapog Method

This method of raising nursery has been introduced in India from Philippines. It has been adopted by some farmers in Andhra Pradesh for raising seedlings. It saves almost half of the time in seedling raising. The main merit of this method is that less area is needed to raise seedlings. Twenty-five to 30 sq m of area is enough to raise seedlings sufficient for planting 1 ha. The seedlings are

raised faster in this method. The seedlings raised by this method are, however, very delicate and survive only for about two weeks. Besides, the seedlings are thin, slender and short in height. The seedlings when allowed to remain in the bed, may dry after two weeks.

In this method, beds could be prepared on an even but slightly raised (4 to 5 cm) surface in an open field or on even cement floor. About 1 sq m of seedbed should be required for every 3 kg of seed. A width of 1.5 m has been found easily manageable. Cover the soil surface of the seedbed evenly and completely with banana leaves with the protruding midribs removed or preferably with plastic sheets. Carefully lay strips of banana bracts along the edge of the seed bed. Push thin bamboo pegs through the bracts into the soil to keep bracts upright and firm.

About 36 to 48 hours pregerminated seeds should be broadcast uniformly over plastic or banana leaves @ 3 kg/sq m. Pack the seeds to make a uniform layer of three seeds thick. Do not press too hard on seeds. Follow this by sprinkling water gently. Sprinkle water three to four times a day up to four days to keep the seedbed wet. Thereafter, cover it with 1 to 2 cm of water till end. Also press the seeds lightly once a day till fourth day and protect them from birds. Dapog seedlings would be ready for transplanting within 11 to 14 days of sowing. The seedlings thus raised can be rolled like a carpet with roots facing outside and carried to the transplanting site. Loosen the interlocked roots carefully before transplanting. Three to four seedlings should be transplanted per hill instead of two.

Mat Type Method

Looking into the labour scarcity, mechanical transplanting is emerging option for paddy transplanting but mat type nursery is prerequisite for mechanical paddy planters (Figs 1.10 and 1.11). Two types of paddy planters are commonly available: i) Walk behind paddy planter which can transplant 2.5 acres per day with the help of 2–3 persons (Fig. 1.12), ii) four-wheel drive self-propelled paddy planter which can transplant 8–10 acres per day with the help of 5 persons (Fig. 1.13). With the help of these planters, the transplanting can be done easily and also facilitate optimum plant population. As transplanting is done in lines which further helps in proper aeration to the plants and spraying to the crop is also easy.

The mat type nursery can be raised on polythene sheet or in trays. After placing the frame on polythene sheet, the soil from the sides is put in the frame. Then seed is placed in the frames by the nursery seeder. Two persons can sow seedlings for 3–4 acres in a day. Tractor operated nursery seeders are also available which spread polythene sheet on the ground, lifts the soil from both the sides and puts on the polythene sheet, and also spread the seed on the soil simultaneously. This machine helps in saving of labour and cost of cultivation by about 60%. The field capacity of the machine is 0.28 acre/hour.

The following points are to be kept in mind while raising mat type nursery:

- Select the mat type paddy nursery location having fertile soil, assured irrigation and minimum transportation distance of location to the field. There should be no stones or other hard material in the soil.



Fig. 1.10: Seed spreading on polythene film by putting iron frame for raising mat type nursery (see Colour Plate 1)



Fig. 1.11: Mat type nursery raising (see Colour Plate 1)



Fig. 1.12: Walk behind paddy planter (see Colour Plate 1)



Fig. 1.13: Four-wheel paddy planter (see Colour Plate 1)

- The field should be preferably laser leveled and 20 m away from tubewells and trees. If required, prior to nursery sowing, mix the farm yard manure into the soil and irrigate the field. Prepare the field at proper moisture.
- Spread polythene sheet 50–60 gauge, 90 cm wide having 1–2 mm diameter perforations over it. Polythene sheets, weighing 270 g spread to a length of about 15 meters (for about 150 mats), are sufficient for preparing seedlings for one acre.
- Place one or more iron frames having compartments of size $45 \times 21 \times 2$ cm for walk behind planter and $58 \times 28 \times 2$ cm for self-propelled transplanter. Number and size of compartments vary according to machine specifications.
- Fill the soil from both the sides in the frames uniformly up to the top surface.
- Spread pre-germinated seed about 50–60 g evenly in each compartment to achieve uniform density of 2 or 3 seedlings/sq cm in the mat. For uniform seed distribution, use nursery sowing seeder. The length of nursery sowing seeder is to be equal to the width of frame and has openings of 1 cm diameter on full length of the roller.
- About 10–12 kg seed is sufficient to sow about 150 mats required for transplanting one acre depending on the frame size. Cover the seeds by a thin layer of soil and sprinkle water by hand sprayer for proper setting of the soil. Seed treatment is done before sowing by soaking the seed in 10 litres of water for 8–10 hours.
- Lift frames and put these at the next place, and repeat the above procedure for sowing the required number of seedling mats.
- After sowing, irrigate the field, but the flow of water for first 2–3 irrigations should be very mild and level should be uniform so that there is no damage to newly formed mats. Care must be taken that the seedling mats are always wet.
- Spray the seedlings after an interval about 10 days with 200 g of urea dissolved in 15 litres of water to 100 mats. The seedling mats become ready after 25–30 days of sowing.
- Drain the water from the nursery field a few hours before nursery uprooting. Give a cut with a sharp blade along the nursery boundaries of the mat. The uprooted nursery mats are ready for transport to the field. One person can uproot 5–6 acres in a day.

By adopting above methods and techniques, farmers can raise healthy mat type nursery and transplant with the help of mechanical paddy planter. Farmers should get trained from nearby Krishi Vigyan Kendra or agriculture department for raising mat type nursery.

PREPARATION OF FIELD

Plough the field 20–25 cm deep by mould board plough in summer to expose the eggs of harmful insects, pests and rhizomes of weeds. Keep it flooded or

saturated with water for about one fortnight before transplanting. This helps in decomposition of chaff and straw of previous crops. Puddling should begin about two weeks ahead of transplanting. Before puddling, an earthen bund, about 30 cm high should be made around the field. The equipment which puddles the field is called puddler. Recently, different types of bullock and tractor drawn puddlers are being used for this purpose. Puddling is a very important operation in transplanted rice. It helps to kill the weeds and buries them in puddled layer. The rate of germination of weeds is also reduced in subsequent growing period of crop. It helps to create beneficial physical, biological and chemical conditions for rice plant growth. Soil surface is left in a more even condition. Puddle the field by three to four runs of puddler in standing water. Apply uniformly half of nitrogen and total quantities of phosphorus and potash on drained surface at the time of last puddling and incorporate in the top 10–15 cm deep soil.

TRANSPLANTING

Transplanting shall be done when seedlings are ready for transplanting. The seedlings are uprooted from the nursery at the optimum age (three to four weeks for short duration varieties and four to five weeks for medium and long duration varieties). Transplanting of the healthy seedlings may be done at the four to five leaf stage or when they are about 15–20 cm high. Delayed transplanting leads to poor tillering, early flowering of the main tillers and reduction in yield. Transplant two to three seedlings per hill at 20×10 cm distance under normal conditions. Increase the number of seedlings per hill if old seedlings are used. For 45 days old seedlings the number of seedlings per hill should be five or six. In alkaline soils old seedlings (45 days old) establish better than young seedlings of 25 days age or so. In each case seedlings should be transplanted at 2–3 cm depth. Seedlings should not be planted deeper than 2–3 cm as deeper planting delays and inhibits tillering. Planting in lines may not be necessary if adequate population is assured. There should be on an average, 50 hills/sq m to assure adequate population in rice field.

In wet or lowland cultivation of rice, transplanting is advantageous for the following reasons:

1. It enables the cultivator to have optimum plant population at desired spacing in the field.
2. It enables the cultivator to have an opportunity to give a thorough cultivation and puddling operation to the field which keeps down the weeds.
3. Since the nurseries occupy only a small area of the field, the control of diseases and insect pests and irrigation and manuring of young crop is easier and cheaper than a broadcast or direct sown crop.

But nowadays transplanting has become very expensive due to high labour cost. A number of field experiments have shown that the productivity of direct seeded rice could be as high as from transplanted rice provided the weeds could be controlled effectively and the management level is high.

BROADCASTING SPROUTED SEEDS IN PUDDLED SOILS

This method is adopted in areas where there is a shortage of labourers or otherwise labour is very expensive for transplanting. In this method the field is prepared and puddled in the same manner as in the case of transplanted rice. About 100 kg seed is required for one hectare. Seeds should be soaked in water and pregerminated before broadcast. Instead of transplanting the seedlings in the puddled field, the sprouted seeds with radicle length 1–2 mm are uniformly broadcast by hand.

MANURES AND FERTILISERS

Organic manures and chemical fertilisers are both important for rice cultivation. Application of bulky organic manures is desirable particularly under upland conditions, to maintain the soil in good physical condition and to increase the water holding capacity of the soil for maximum utilisation of rain water. About 10–15 tonnes of well rotted farm yard manure or compost /ha should be applied 4 to 6 weeks before sowing.

Application of chemical fertilisers depends basically upon the fertility status of the field, previous crop grown and amount of organic matter added. Soil testing is the simplest and easiest scientific method to know the quantity of nitrogen, phosphorus and potassic fertilisers that are needed to get optimum rice yield in a field.

Soil fertility is a very variable factor. It varies in different agroclimatic zones. A generalised fertiliser recommendation does not take into account the variability in soil fertility and cannot assure optimum yield levels from the crop. Most agriculture departments and agricultural universities in India have formulated fertiliser recommendations for rice appropriate to local conditions. The fertiliser doses recommended by the Agriculture Departments in different states are given in Table 1.8.

Fertiliser management in transplanted paddy field is different from upland rice because continuous submergence of the field creates conditions which are not obtained in upland well-drained fields. Presence of excess water in paddy fields sets in a series of reactions—physical, chemical and biological in the soil. The root zone is converted from aerobic to anaerobic environment. It is this anaerobic environment in the paddy soil which is responsible for gaseous loss of fertiliser nitrogen by denitrification process and also causes changes in the behaviour of phosphorus as well as micronutrients especially iron and manganese.

The low land puddled soils remain waterlogged during the entire growth period of the crop. The important change in the soil due to water logging condition is the conversion of the root zone of the soil from an aerobic to anaerobic environment due to depletion of oxygen in the soil profile. The flooded or waterlogged puddled soil develops two zones. The upper zone (1 to 10 mm thick) receives oxygen periodically from fresh supplies of irrigation

Table 1.8: Fertiliser doses recommended for rice in different states

State	Season	Variety	Recommended dose (kg/ha)		
			N	P ₂ O ₅	K ₂ O
Andhra Pradesh	Kharif	HYV	60	40	50
	Rabi	HYV	120	60	50
	Kharif	Local	40	40	50
	Rabi	Local	80	40	50
Asom	Kharif/Rabi	HYV	80	40	40
	Kharif/Rabi	Local	30	15	15
Bihar	Kharif	HYV	85	50	40
Gujarat	Kharif	HYV	100	50	50
	Kharif	Local	50	25	–
Haryana	Kharif	HYV	120	60	60
	Kharif	Local	60	30	–
Himachal Pradesh	Kharif	HYV	90	40	40
	Kharif	Local	50	25	25
Karnataka	Kharif	HYV	100	50	50
	Summer	HYV	120	60	60
Kerala	Kharif	HYV	90	45	45
	Kharif	Local	40	20	20
Madhya Pradesh	Kharif	HYV	100	25	–
	Kharif	Local	37.5	50	50
Maharashtra	Kharif	HYV	100	50	50
	Kharif	Local	25	25	25
Punjab	Kharif	HYV	125	30	30
	Kharif	Local	62.5	30	–
Odisha	Kharif	HYV	125	60	60
	Rabi	HYV	125	30	30
Tamil Nadu	Kharif	HYV	120	60	60
	Kharif	Local	50	35	15
Uttar Pradesh	Kharif	HYV	120	60	60
	Kharif	Local	60	30	30
West Bengal	Kharif	HYV	60	50	50
	Rabi	HYV	100	70	70

HYV: High yielding variety

water turns brown in colour called 'oxidised zone' and reacts like an unflooded upland soil. The remaining lower portion of puddled soil without oxygen is called 'reduced zone'. Ammoniacal nitrogen fertilisers when applied in such a soil system, get oxidised to nitrate form (NO₃⁻) in the oxidised zone (surface layer of the soil). This nitrate nitrogen in turn leaches down to the reduced zone (sub-surface layer) and gets denitrified to gaseous nitrogen. This loss of nitrogen can be prevented by incorporating ammoniacal nitrogen into the reduced zone of the soil where it is held.

Fertilisers containing nitrate such as calcium ammonium nitrate (CAN), ammonium sulphate nitrate (ASN) and certain NPK complex fertilisers or mixtures are more susceptible to loss of nitrogen through leaching and denitrification than are urea, ammonium sulphate, ammonium chloride or NPK complex fertilisers containing no nitrate. Use of nitrate fertilisers should, therefore, be avoided in paddy. Diammonium phosphate (DAP) is an excellent fertiliser for basal dressing in paddy fields.

Sulphur-coated urea has been found better than normal urea for paddy fields where flooding is delayed or intermittent. In acid soils, rock phosphate in finely powdered form can be used as phosphorus source with advantage but it should not be applied in neutral or alkaline soils.

METHOD AND SCHEDULE OF FERTILISER APPLICATION

For best results, apply full dose of phosphorus and potash and half dose of nitrogen before last puddling. Remaining half dose of nitrogen should be applied in two equal doses, first at tillering stage (25–30 days after transplanting) and second at panicle initiation stage (55–65 days after transplanting). In the case of transplanting of old age seedlings, two-thirds to three quarters of total nitrogen should be applied at the time of transplanting and rest 25 days later.

Method of application of nitrogen fertiliser is crucial in paddy, in view of the fact that hardly 30–40% of the applied nitrogen is actually used by the rice crop. The unused portion also does not stay in the soil; rather it is lost mainly through leaching and denitrification. Till now there is no practical and economic way to completely check this loss but recently some techniques have been developed which can minimise the losses, substantially. A few of them, which are suitable under Indian conditions, are given as follows:

Use of Pre-incubated Urea

Mix urea with moist soil (not too wet) @ 1 kg urea with about 5 kg soil. Allow this mixture to stand in shade for 36–48 hours before applying in the field.

Use of Mud Balls

Prepare small balls of moist soil and put urea or any other fertiliser in the centre of the ball. Close the opening and allow to dry a little, if possible. Use these balls in the paddy fields where it is not possible to drain out the water from the field at the time of fertiliser application in standing crop.

Use of Neem Seed Cake

Finely ground neem seed cake is mixed with urea @ 15–20%. Karanj or mahua cakes can also be used in a similar way. These oilcakes delay nitrate formation from urea and thus reduce the possibility of nitrate loss through denitrification or leaching.

In zinc deficient soils 20–25 kg of zinc sulphate/ha should be applied at the time of last puddling.

WATER MANAGEMENT

Since the water requirement of rice is higher than that of any other crop of a similar duration, assured and timely supply of irrigation water has a great influence on the yield of the crop. In the life cycle of rice plant there are certain critical stages when water requirement is high. The water requirement is high during the initial seedling period covering about 10 days. Tillering to flowering is the most critical stage when rice crop should not be subjected to any moisture stress. Ensure enough water from panicle initiation stage to flowering (heading). Flooding is not necessary if weeds can be controlled economically through chemical means or by manual weeding before the plants become vegetatively strong. Application of small quantities of water at short intervals to keep the soil saturated is more effective and economical than flooding at long intervals. Flooding is not necessary if the soil is saturated with water and biofertilisers have not been used. However, flooding suppresses the weed growth. It increased the availability of many nutrients, particularly phosphorus, potassium, calcium, iron and silica.

Irrigation and Drainage

Keep the water standing continuously in the crop for two weeks only after transplanting so that the seedlings get properly established. Afterwards, alternate wetting and drying (AWD) method can be practised for saving of irrigation water. In alternate wetting and drying method, apply irrigation two to three days after the ponded water has infiltrated into the soil. Every care should be taken that field does not develop cracks. In this way, irrigation water can be saved without causing any reduction in yield. The depth of standing water should not exceed 10 cm. Drain away excess water before interculture or weeding and irrigate the field after these operations. Stop irrigation about a fortnight before maturity to facilitate easy harvesting and the timely sowing of the succeeding rabi crop.

WEED CONTROL

Though there is less problem of weeds in transplanted rice, sometimes weeds emerge when the soil is exposed to atmosphere as submergence is not possible continuously. Under such conditions yield may be reduced from 20 to 40%. The most commonly found weeds in transplanted rice are given as follows:

1. *Echinochloa colonum*
2. *Echinochloa crus-galli*
3. *Cyperus iria*
4. *Eclipta alba*
5. *Celosia argentia*
6. *Dactyloctenium*
7. *Setaria glauca*
8. *Monocharia* spp.

9. *Cyperus difformis*
10. *Scirpus* spp.
11. *Fimbristylis litoralis*

Weeds should be removed once at 20 days after transplanting (before first top dressing) and second time at 50–60 days after transplanting (before second top dressing). However, the control of weeds with herbicides is both efficient and economical. A number of herbicides have been found quite effective in controlling annual weeds of grassy and broad-leaf weeds as indicated in Table 1.9. Use of any of these pre-emergence, early post-emergence and post-emergence herbicides provides effective control of *swank* and moderate control of other weeds. Any of the herbicide listed in Table 1.9 may be applied by mixing with 150 kg of sand per hectare in standing water within 2 to 3 days of transplanting. It is always better to use different group of recommended herbicides in rotation to avoid the problem of herbicide resistance in weeds.

Table 1.9: Herbicides used in paddy for control of grassy and broad-leaved weeds

Name of herbicides and brand	Dose per hectare	Remarks
Machete/Delchlor/Rasayanchlor/Excchlor/Punch/Hiltachlor/Thunder/Teer/Capchlor/Trapp/Milchlor/Narmadachlor/Fychlor/Arochlor/Megachlor/Butachlor-Sunbeam/Markchlor/Paklor/Butacid/Jaibutachlor 50 EC (butachlor)	3000 ml	These herbicides are highly effective against <i>swank</i> and give moderate control of other weeds
Fast-mix 50 EW (butachlor)	3000 ml	
Arozin 18 EC (anilofos)	2000 ml	
Arozin/Aniloguard/Libra/Pestoanilofos/Padigard 30 EC (anilofos)	1250 ml	
Stomp 30 EC (pendimethalin)	2500–3000 ml	In case of pendimethalin, use lower dose on light textured soil and higher dose on medium to heavy soils
Rifit Plus 37 EW (pretilachlor)	1850 ml	Use hand gloves while applying these herbicides
Sathi 10 WP (Pyrazosulfuron ethyl)	150 g	
Topstar 80 WP (oxadiargyl)	112 g	

Early post-emergence (within 10–12 days of transplanting): Early post-emergence spray of 100 ml/ha Penoxsulam (Granite 240 SC) at 10–12 days of transplanting in 350–400 litres of water, particularly in fields where continuous standing of water is a problem, provides effective control of grass weeds including *swank*, paddy *mothas* and broadleaf weeds in transplanted rice. Do not spray the herbicide in the standing water and irrigation may be applied one day after spray.

Post-emergence (within 20–25 days of transplanting): For the effective control of *swank* and paddy *mothas*, spray 250 ml/ha bispyribac 10SC (Nominee Gold/

Wash out/Macho/ Taarak 10 SC) using 350–400 litres of water, at 20–25 days of transplanting. In crop infested with *Leptochloa* and *kanki*, apply 1000 ml per hectare fenoxaprop 6.7 EC (Ricestar) at 20–25 days of transplanting in 350 litres of water. Do not spray the herbicide in standing water and irrigation may be applied one day after spray.

Control of sedges and broadleaf weeds: For control of sedges (paddy *mothas* and broadleaf weeds including *ghrilla*, *sanni*, etc., spray 75 g per hectare metsulfuron (Algrip20 WG) or 125 g ethoxysulfuron (Sunrice15 WP) or 20 g per hectare metsulfuron methyl + chlorimuron ethyl (Almix 20 WP) if the crop is infested with paddy *mothas* in 350–400 litres of water at 20 days of transplanting. Do not spray the herbicide in standing water and irrigation may be applied one day after spray. The spray should be done on a clear and calm day for getting good efficacy from herbicides. Delay in application of herbicides results in poor control of weeds.

BASMATI RICE

The exquisite aroma and unique cooking properties of Basmati rice, also known as the “scented pearl”, make it a premium agricultural commodity with high export potential. ‘*Bas*’ in Hindi language means “aroma” and ‘*Mati*’ mean “full of”, hence the word Basmati, i.e. full of aroma. Basmati, which is grown for more than 250 years in the Indian subcontinent, fetches almost three times higher price than the conventional rice. Apart from its distinct aroma and linear kernel elongation during cooking, its fluffy texture, easy digestibility and palatability make basmati cuisines an inimitable gourmet’s delight. It is also known to have low glycemic index, making it suitable for diabetic consumers.

Traditional Basmati varieties are tall, prone to lodging, photoperiod and temperature sensitive and very low yielding, therefore, their production and productivity were very limited. Initial research efforts on Basmati rice improvement based on germplasm collection, evaluation and selection led to the identification of a line number 370/27 which was later on released as “Basmati 370” for cultivation in 1933. This variety was the most popular variety for the purpose of export until the late 1980s. However, Basmati rice did not acquire a status of a commercial enterprise until the Indian Agricultural Research Institute (ICAR-IARI), New Delhi, took the lead to improve the plant type through systematic research spanning five decades starting from the late 1960s. Pioneering research work was carried out at the ICAR-IARI, New Delhi, during the 1970s on standardization of protocols for estimating various Basmati quality parameters and analyzing their inheritance pattern. Similarly, defining the attributes of Basmati rice is also very important with the research efforts put for developing high yielding and short duration Basmati varieties.

The specific definition of Basmati rice given by the Export Act 1963 (modified in 2003) of Government of India specifies certain conditions to satisfy a variety as a Basmati rice variety like it should be grown in Indo-Gangetic Plains only. Its grain should have exceptional length (minimum average precooked milled rice length is 6.61 mm), which would increase substantially after cooking

(average volume expansion ratio >3.5), after cooking the grain should have high integrity, high discreteness and distinct aroma, taste and mouth feel. A traditional Basmati variety can be land races or varieties of uniform shape, size and colour recognized as Basmati variety. Similarly, evolved Basmati variety would be the one whose one of the parents is a traditional Basmati variety. Thus, for any variety to be called a Basmati rice variety, it must be tested and evaluated under National Basmati Trails as a part of All India Coordinated Rice Improvement Project, ICAR-IIRR, Hyderabad, and released/notified under the Seed Act 1966 of Government of India. Basmati is primarily grown in the Indo-Gangetic region of north-western region comprising the seven states Punjab, Haryana, Himachal Pradesh, Uttarakhand, Jammu and Kathua districts of Jammu and Kashmir, and 27 districts of western Uttar Pradesh. This region has been earmarked as the Geographical Indication (GI) for Basmati rice and the GI status has been conferred to Basmati rice in 2016 (GI No. 145 of the Geographical Indication Registry, Government of India, *vide* certificate No. 238 dated 15.02.2016). India is the largest cultivator and exporter of Basmati rice, followed by Pakistan. More than 90 percent of Indian Basmati is produced in Punjab, Haryana and Uttarakhand. Basmati rice from the Indian subcontinent is highly prized in the international market for its unique grain, cooking and eating quality.

Once limited to the Indian subcontinent, large scale commercial expansion and trade liberalization helped Basmati capture markets in Europe, United States and the Middle East. Among Middle East countries, countries like Iran, Saudi Arabia, Iraq, Kuwait and the United Arab Emirates are the major importers of Basmati. The decadal average during 2004–14 suggests that the Basmati export constituted about 43.7 percent of the total Indian rice exports to the maximum of 95 percent during 2010–11, whereas its production was only about six percent of India's total rice production. During 2014–15, as compared to the 2005–06, the Indian Basmati rice exports witnessed a compound annual growth of 27 percent in terms of export monetary value. The domestic price of Basmati that farmers fetch is directly linked to the cyclical price fluctuations in the international market. Higher prices in one year motivates farmers to grow more in the next year, thereby decreasing the price due to increased supply. Since the Basmati has low yield compared to coarse grain rice, basmati fetches higher income to the farmers only when they get higher price. Basmati is not consumed in India to a considerable level; the major market for Indian Basmati is placed abroad. Therefore, if there is increase in production of Basmati rice, there is a risk of glut in the export market and Indian exporters may not get the price they desire. This may lead to decrease in the price paid to the Basmati growers.

Till 2017, about 29 Basmati varieties [Basmati 217, Basmati 370, Type 3 (Dehraduni Basmati), Punjab Basmati 1 (Bauni Basmati), Pusa Basmati 1, Kasturi 615, Haryana Basmati 1, Mahi Sugandha, Taraori Basmati (HBC 19/Karnal Local), Ranbir Basmati, Basmati 386, Improved Pusa Basmati 1 (Pusa 1460), Pusa Basmati 1121 (after amendment), Vallabh Basmati 22, Pusa Basmati 6 (Pusa 1401), Punjab Basmati 2 1708, Basmati CSR 30, Malviya Basmati Dhan 10-9,

Pusa Basmati 1121: A Multi-billion Dollar Earning Basmati Variety

Pusa Basmati 1121 (PB 1121) is a landmark variety having Basmati quality traits introgressed from traditional Basmati varieties such as Basmati 370 and Type 3. Pusa Basmati 1121 was developed by ICAR-IARI, New Delhi and released for commercial cultivation in 2003. This variety yields nearly 5.0 t/ha with a duration of 140–145 days as compared to traditional Basmati varieties yielding only 2.5 t/ha in around 160 days. The most striking feature of Pusa Basmati 1121, as compared to other Basmati rice varieties, is its kernel length of 21.50 mm after cooking. As a result of its improved kernel elongation, the volume expansion in the cooked rice is more than 4.0 times along with appealing taste, good mouth feel and easy digestibility. This helps in realizing more cooked rice volume with lesser milled rice, a trait most preferred in the household as well as the hotel industry which has set new standards in Basmati rice market. Owing to its higher yield and unique grain and cooking quality traits, Pusa Basmati 1121 received phenomenal acceptance in the domestic as well as global market, thus fetching premium prices in the international market.

The area under Basmati cultivation increased from 0.78 million hectares (mha) in 2004 to 2.12 mha in 2015, in which Pusa Basmati 1121 was cultivated on almost 70% of area. The total Basmati produced during *Kharif* 2016 was 6.16 million tonnes (mt), out of which PB 1121 contributed 68% share (4.39 mt). During 2003–04, the total foreign exchange earning of Basmati was only 440 million USD (prior to release of PB 1121). Owing to the superior cooking quality traits of PB 1121, the annual foreign exchange earning of Basmati has surged to 4.87 billion US Dollars (USD) during 2013–14 in which the contribution of PB 1121 was 3.41 billion USD (equal to Rs. 22000 crores). The cumulative earning from its export and domestic use (2008 to 2016) is estimated to be about 20.80 billion USD. After release of PB 1121, the volume of Basmati export has increased by 4.4 times and the value increased by 6.8 times compared to the same period before its release. This has immensely helped in creating employment in the Basmati growing region, which has resulted in the establishment of more modern rice mills and making available better quality Basmati rice for the domestic and global market on a regular basis. It has greatly improved the economics of Basmati cultivation, and also the entire value chain of the Basmati industry, especially exporters and consumers, thereby ushering in a Basmati rice revolution.

Source: Indian Agricultural Research Institute (ICAR), Pusa, New Delhi

Vallabh Basmati 21, Pusa Basmati 1509, Basmati 564, Vallabh Basmati 23, Vallabh Basmati 24, Pusa Basmati 1609, Pant Basmati 1, Pant Basmati 2, Punjab Basmati 3, Pusa Basmati 1637, Pusa Basmati 1728] have been notified in India and these are being utilized for domestic purposes and international trade. The major characteristics of prominent varieties of basmati rice are described in Table 1.10.

An intensive program on Basmati rice breeding has led to the development of a landmark rice variety, Pusa Basmati 1121, which was developed by the

Table 1.10: Prominent varieties of Basmati suitable for northern India

<i>Variety</i>	<i>Major characteristics</i>
(i) Photoperiod Sensitive Varieties (Short day length initiates flowering)	
Punjab Basmati 5 (2017)	It is a semi-dwarf Basmati variety (112 cm) released in 2017. It possesses extra-long slender grains with excellent cooking and eating quality characteristics. The grains almost double upon cooking are non-sticky and highly aromatic. It matures in about 137 days after seeding with average yield of 3.75 t/ha.
Punjab Basmati 4 (2017)	It is high yielding, semi-dwarf (96 cm), lodging tolerant Basmati variety released in 2017. The grains are extra-long slender with excellent cooking and eating quality characteristics. It matures in about 146 days after seeding with average yield of 4.25 t/ha.
CSR 30 (2017)	CSR 30 is developed by CSSRI, Karnal and released in 2017. It is about 139 cm tall and possesses extra-long slender grains with excellent cooking and eating quality characteristics. The grains are non-sticky, soft to eat and highly aromatic. It matures in about 142 days with an average yield is 3.37 t/ha.
Punjab Basmati 3 (2013)	It is a semi-dwarf lodging tolerant variety which is about 105 cm tall. It possesses extra-long slender grains with tip awns which prevent bird damage. The grains are translucent with strong aroma, good cooking and eating quality characteristics. The cooked rice is non-sticky and soft to eat. It matures in about 139 days with average yield of 4.0 t/ha.
Punjab Basmati 2 (2008)	This variety is about 125 cm tall. It possesses extra long slender grains with excellent cooking and eating qualities. Grains of this variety are strongly scented. Grains, almost double upon cooking, are non sticky and soft to eat. It matures in about 140 days with average yield of 3.15 t/ha.
(ii) Photoperiod Insensitive Varieties (flowering unaffected by day length)	
Pusa Basmati 1	It is semi-dwarf and high yielding Basmati variety matures in 135 days and average yield is 5.0 t/ha.
Pusa Basmati 6	It is semi-dwarf and high yielding Basmati variety with strong culm and less chalky grains (< 4%) with very strong aroma. It matures in 150 days and average yield is 5.5 t/ha.
Pusa 1612	It is semi-dwarf early maturing long slender aromatic rice variety which is resistance to blast disease. It matures in 120 days and average yield is 4.6 t/ha.
Pusa Basmati 1609	It is semi-dwarf early maturing variety with resistance to blast disease. It matures in 120 days and average yield is 5.1 t/ha.
Pusa 1592	It is semi-dwarf early maturing long slender aromatic rice variety with resistance to bacterial blight disease. This variety matures in 120 days and average yield is 4.73 t/ha.
Pusa Basmati 1121 (2008)	It is about 120 cm tall. It possesses extra long slender grains with good cooking quality. It has longest cooked rice length among all the aromatic rice varieties recommended for Punjab. It matures in about 140–145 days after seeding. It is susceptible to all the pathotypes of bacterial blight pathogen prevalent in the state. Its average grain yield is 5.00 t/ha.

(Contd.)

<i>Variety</i>	<i>Major characteristics</i>
Pusa Basmati 1509 (2013)	It is an early maturing variety which matures in about 120 days after seeding. Its average height is 92 cm. It possesses extra-long slender, grains with excellent cooking and eating quality characteristics. Its grains become almost double upon cooking and are scented. It is suitable for multiple cropping systems. Its average paddy yield is 4.92 t/ha.
Pusa Basmati 1637 (2018)	It is a new version of Pusa Basmati 1 which is moderately tolerant to blast disease. Its average plant height is 109 cm and matures in 138 days after seeding. It possesses extra long slender grains. Its average yield is 4.37 t/ha.
Pusa Basmati 1718 (2019)	It is a bacterial blight resistant version of Pusa Basmati 1121 having average plant height is 121 cm and matures in 135 days. It possesses extra long slender grains with good cooking quality. Its average yield is 4.25 t/ha.

ICAR-IARI, New Delhi. This proved to be a high-yielding unique Basmati rice variety with extra-long slender grains, exceptional kernel length after cooking (22–25 mm), intermediate amylose content, high cooked kernel elongation ratio (2.5 times), high volume expansion after cooking (>4 times), and a strong aroma. These unique properties of Pusa Basmati 1121 have caught the fancy of traders worldwide. IARI, New Delhi, is fully devoted to develop early maturing, high yielding and disease resistance varieties of basmati and Pusa Basmati 1509 (early maturing), Pusa Basmati 1718 (resistant to bacterial leaf blight), Pusa Basmati 1637 (moderately tolerant to blast) are some such examples. Detail of important characters of popular basmati varieties is given separately. Agronomic practices like land preparation, seed rate and seed treatment, method of nursery raising, weed control, etc. are almost the same for Basmati varieties as for other semi-dwarf rice varieties.

The increasing trend in the productivity of basmati rice is a good sign for agriculture which implies increased use of inputs such as fertilisers, pesticides, weedicides, etc. Considering specifications of international market, particularly in markets like USA and EU, the Indian basmati must meet their quality requirements. Due to the big boom in basmati export and the race to produce more from a unit area led to incorporating more and more inputs into the farm. Presence of pesticides residues is the most common reason given to either totally ban or reject a few of the consignments of basmati. Exporting basmati needs to follow international quality standards right from farms, traders to exporters to earn maximum foreign currency. Problems of adulteration, varieties mix, pesticide residues, infringements, etc. must be addressed with due concern to establish Basmati as a gem of Indian delight across the globe.

DISEASES

Diseases cause on an average, about 10% reduction in yield, which may go up from 50 to 90% in severe cases. Symptoms and suitable control measures for major diseases are given as follows.

Blast

It is caused by *Pyricularia oryzae*. Boat or eye-shaped spots with grey or dark brown margin appear on the leaf and leaf sheath. The central portion of the young spot becomes pale-green or dull-greyish-green and appears water-soaked but in older spots the central portions turn grey or straw coloured. In severe condition, spots may coalesce to form large blighted spots. At the time of panicle emergence, the stem below the earhead gets infection and turns into brown to black spots which may cover the entire stem and stop the translocation of food. The grains remain empty. Application of heavy dose of nitrogen, high atmospheric relative humidity (86–98%) and night temperature around 20°C for few hours are conducive for the disease.

Control Measures

- The disease is more severe on Basmati cultivars and under application of heavy nitrogenous fertilizers. For Basmati, grow Pusa Basmati 1637, Pusa Basmati 1718 which are moderately tolerant to blast.
- For Basmati rice, do not apply nitrogenous fertiliser if sown after green manuring.
- Grow field resistant varieties recommended for your area as mentioned in details of varieties
- Spray the affected crop with 500 ml Amistar Top 325 SC (azoxystrobin + difenconazole) or 1200 g Indofil Z-78, 75 WP (zineb) per hectare in 500 litres of water, at the boot and ear-emergence stages.

Brown Leaf Spot

This disease is caused by *Drechslera oryzae* and produces oval, eye-shaped spots with a conspicuous dark-brown dot in the centre and light brown margin. Spots are also produced on the grains. This disease occurs in poor soils, therefore, give adequate and balanced nutrition to the crop.

Control Measures

- To control the disease, give two sprays of 80 g Nativio 75 WG (trifloxystrobin + tebuconazole) in 200 litres of water/acre. First spray at boot stage of crop and second spray after 15 days.

Stem Rot

This disease is caused by *Sclerotium oryzae*. The fungus affects the stem at earing and black lesions are produced on the sheath at water level. Later on, the stem gets infected and rots leading to withering and lodging of the plant. The incidence of this disease has declined on high yielding varieties due to improved cultural practices. Destroy the diseased debris of infected crop.

Control Measures

- Avoid excessive irrigation and use recommended dose of nitrogenous fertiliser. Avoid ponding of water for a longer period. Drain the standing water from time to time.

- Grow field resistant varieties recommended for your area as mentioned in details of varieties
- Destroy the infected stubbles and use treated seed only.

False Smut

It is a fungal disease caused by *Ustilaginoidea virens* in which the individual grains transform into large yellowish/greenish velvety spore-balls. High relative humidity, rainy and cloudy days during the flowering period increase the incidence of the disease. The application of organic manures and high dose of nitrogenous fertilisers also increase the intensity of attack.

Control Measures

- Use certified seed from reliable source.
- Collect the diseased grains and destroy them as soon as possible. This will check the secondary spread and will also help in reducing the inoculum for next year.
- To control this disease, give spray of 1000 ml Galileo Way 18.76 SC (picoxystrobin + propiconazole) or 1200 g Kocide 46 DF (copper hydroxide) in 500 litres of water per hectare at boot stage of the crop in disease prone areas.

Sheath Blight

This disease is caused by *Rhizoctonia solani*. Symptoms of this disease result into greyish green lesions with purple margin develop on the leaf-sheath above the water level. Later, the lesions enlarge and coalesce with other lesions. Its severe attack results in the poor filling of the grains.

Control Measures

- Destroy the rice straw and stubbles after harvesting the affected crop.
- Avoid the excessive use of nitrogenous fertilizers.
- Keep the bunds clean by removing the grass.
- As soon as the disease appears at maximum tillering to boot stage, spray 1000 ml Galileo Way 18.76 SC (picoxystrobin + propiconazole) or 500 ml Amristar Top 325 SC or Tilt/Bumper/Pikapika 25 EC (propiconazole) or Folicur/Orius (tebuconazole) 25EC or 200 g Nativo 75 WG (trifloxystrobin + tebuconazole) or 800 ml Lusture 37.5 SE (flusilazole + carbendazim) or 500 ml Monceren 250 SC (pencycuron) or 500 g Bavistin 50 WP (carbendazim) in 500 litres of water. Give second spray 15 days thereafter.

Bacterial Leaf Blight

This disease is caused by *Xanthomonas oryzae*. The 'Kresak' occurs in early stage of plant growth in which the plant withers and dries up. In the later stage, the blighting starts from the tip of the leaves from one or both the margins or in the centre and proceeds downwards. The leaves turn straw yellow. Yellowish bacterial ooze appears on the surface which dry into bead-like

encrustations, if there is no rain for a few days. In diseased plants, grains are partially filled or become chaffy causing heavy loss in yield.

The pathogen remains viable in infected rice stubbles and seeds. In those areas where two crops of rice are grown pathogen continues from crop to crop. It has also been reported to survive on some weed host plants.

Control Measures

In order to mitigate the losses, adopt the following integrated measures:

- For the management of bacterial blight, grow resistant rice varieties recommended for your area as mentioned in details of varieties.
- Use disease free seed.
- Do not grow nursery and crop under shade and near wheat straw stack
- Do not apply excessive dose of nitrogen. Nitrogen should not be applied beyond six weeks after transplanting (except when leaf color chart is used).
- Spray the crop with 1.5% potassium nitrate at boot stage to reduce sterility.
- Avoid continuous ponding of water in the field.

Bacterial Leaf Streak

It is caused by *Xanthomonas translucens* f. sp. *oryzicola*. In the initial stage, there are water-soaked to translucent inter-veinal narrow streaks which are restricted by the veins and soon turn yellow to orange-brown. These streaks may coalesce to form large patches which may cover the entire leaf surface. Minute yellow to amber coloured beads of bacterial exudates are observed abundantly on the streaks.

Primary infection of the disease occurs through infected seeds, whereas the secondary spread of the pathogen occurs through rain droplets and irrigation water and also through contact between healthy and diseased leaves.

Control Measures

The following measures provide effective control:

- Use certified seed from a reliable source or treat the seed as mentioned earlier.
- Give two sprays of Streptocycline 12 g or Agrimycin-100, 75 g in 500 L of water/ha. The first spray should be given as and when the initial symptom at the disease is observed followed by another spray after 10–12 days.
- Grow resistant varieties.

Tungro Virus

This disease is caused by a virus. Older leaves turn yellow orange starting from the tip and margin. Plants become stunted and bear poor panicles with empty glumes showing dark brown colour on young leaves. Interveinal chlorosis is observed.

The virus is transmitted from diseased plant to healthy plant by the nymph, male and female of rice green leaf hoppers. After 30 minutes of feeding of

diseased plants, hoppers become capable to transmit the virus which continue transmission till virus remain in stylet. Most of the hoppers lose their transmitting ability after 24 hours.

Control Measures

The following steps may provide effective control.

- The green stubbles should be uprooted and destroyed after harvest.
- Isolated plants showing disease symptoms in the beginning should be uprooted and destroyed so that insect does not get inoculum to spread on healthy plants.
- The vector can be controlled effectively by spraying 235 ml Pexalon 10 SC per hectare for the management of plant hoppers. Repeat the spray if population is beyond economic threshold level.
- Grow resistant varieties like Nua Dhusara (CR Sugandh Dhan 3), ASD 16, BPT 5204, CR 1009 and Shatabdi.

Bunt/Kernel Smut

This disease is caused by *Neovossia horrid* and only a few grains in the panicle are infected. Frequently, only a part of the grain is replaced by a black powder. Sometimes, entire grain is also attacked and the black powder scatters on to other grains or leaves, and this is often the easiest way to detect the disease in the field. Also avoid heavy doses of nitrogenous fertilisers.

Sheath Rot

This disease is caused by *Fusarium moniliforme* and the rot occurs on the uppermost leaf-sheaths where oblong to irregular and grey-brown to light-brown lesions develop. The lesions often coalesce to cover the entire sheath. In severe cases, young panicles either do not emerge or emerge partially. A white-powdery growth of the fungus appears on the panicle inside the sheath. The glumes of infected florets are discoloured, dark-red or purple brown to black and often do not fill. The fungus over-winters in rice straw and grains. Destroy the rice straw after harvesting the infected crop. Use disease free seed for sowing.

Bacterial Leaf Streak

This disease is caused by *Xanthomonas oryzae* pv. *oryzicola*. Small translucent streaks appear in the interveinal areas of the leaf. The streaks gradually enlarge and turn reddish, when the plants near maturity. Use disease free seed.

Root-knot Nematode

This disease is caused by nematodes (*Meloidogyne graminicola*). The disease first appears in uneven yellow patches. The affected seedlings show poor and patchy growth with chlorotic symptoms and characteristic terminal hook or bead like galls on the roots.

Control Measure

For the management of root knot nematode, apply mustard cake @ 40 g per square metre 10 days before sowing of nursery with last preparatory tillage operation. Also, practice puddling for nursery sowing. Exercise waiting period of 10 days between application of mustard cake and sowing of nursery.

Khaira

The disease is caused by zinc deficiency. Usually appears in nursery but may appear, in patches, after 10–15 days of transplanting. Growth of the diseased plant is stunted. High yielding varieties show chlorosis between the veins of new leaves, where brown spots are formed. On lower leaves, a large number of small, brown to bronze spots appear, which coalesce to form bigger spots and ultimately the entire leaf turns bronze coloured and dries. Root growth is also restricted and usually the main roots turn brown. The finer roots are destroyed. In severe cases, plants fail to grow further and produce no ears but sometimes there is natural recovery after 6 weeks of age.

Control Measures

- If the previous crop in the field showed the symptoms of zinc deficiency, apply 60 kg of zinc sulphate heptahydrate (21%) or 40 kg zinc sulphate monohydrate (33%) per hectare at puddling.
- If the deficiency is noticed in the growing crop, apply this quantity of zinc sulphate as soon as possible.
- If the deficiency is noticed in nursery, it can also be controlled by spraying a mixture of 5 kg zinc sulphate and 2.5 kg lime in 1000 L of water after 10 days of sowing in nursery, repeat second spray at 20th day. Give third spray in the field after 15–20 days of transplanting, if symptoms appear in the field.
- In highly deteriorated soils, the symptoms of zinc deficiency sometimes appear in patches even after the application of the recommended dose of zinc sulphate. In that event, broadcast 25 kg of zinc sulphate heptahydrate or 16 kg zinc sulphate monohydrate per hectare mixed with an equal quantity of dry soil on the affected patches.

Important points for integrated disease management in rice

- To prevent rice diseases, avoid excessive use of nitrogen.
- Early transplanting, excessive ponding of water, continuous dizzling, 25–30°C temperature and high relative humidity are favourable for development of diseases.
- Monitor the crop for sheath blight appearance and apply recommended fungicides for its timely management.
- Spray should be done on clear days and spray should be as uniform as possible for better results.
- For the management of false smut, apply preventive application of recommended fungicide at boot stage.

INSECT PESTS

Rice crop is attacked by a large number of insect pests right from nursery till the harvest of the crop. A brief description of the major ones, their nature of damage and appropriate control measures are given below:

Stem Borer

Damage caused by the larva of this insect results in 'Dead heart' and 'White head'. Both types of damages result from the feeding of larvae within the stem. They bore and feed inside the stem. They cut the growing parts of the plant from the base causing the plant to die. The drying of growing part of the plant is known as 'dead heart'. Dead heart is created in early life of the plant before flowering and 'white head' occurs at flowering resulting in drying of the entire panicle. Moths may be seen flying around or floating on water in the field.

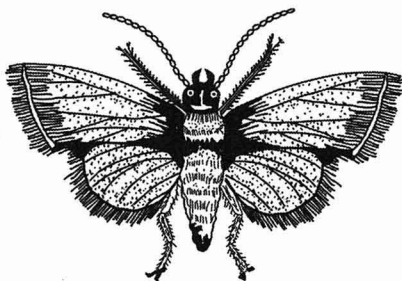


Fig. 1.14: Moth of stem borer

Control Measures

1. Survey the fields and observe the economic threshold level (ETL) of the insect for need based insecticides application. If the fields showing more than 5% dead hearts (ETL) should be sprayed with 50 ml flubendiamide (Fame 480 SC) or 425 g of cartap hydrochloride (Mortar 75 SG) or 2.5 litre of chlorpyrifos 20EC (Coroban/Dursban/Lethal/Chlorguard/Durmet/Classic/Force) in 750 litres of water per hectare.
2. Further application of any of these insecticides may be repeated as and when damage reaches economic threshold level.

Gall Midge

In midge affected plants, regular tillers are transformed into tubular galls, resembling the leaf of onion. These are known as 'onion leaf'. This is a sucking type of insect and sometimes causes serious damage to the growing crop. Tillers that have galls do not produce panicles.

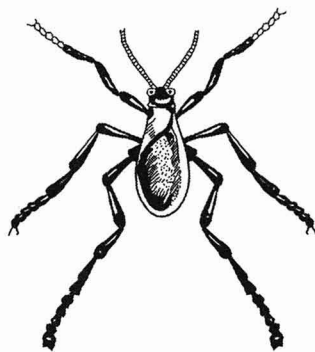


Fig. 1.15: Gall midge

Control Measures

1. If there are 5% or more affected tillers/sq m, adopt the same measures as suggested for the control of stem borer.
2. Grow resistant varieties as recommended for your area in Table 1.2.

Rice Hispa

The adults of this insect scrap on upper surface of leaf blade, leaving only lower epidermis. Damaged areas show white streaks parallel to midrib. Grubs mine between two epidermal layers producing irregular longitudinal white mines.

Control Measures

If the attack starts in nursery, clip-off and destroy the leaf tips of the affected seedlings before transplanting.

On the transplanted crop, spray 2 litres of Ekalux 25 EC (quinalphos) or 2.5 litres of chlorpyrifos 20EC in 750–800 litres of water per hectare with a manually operated sprayer. Repeat the spraying if the attack persists.

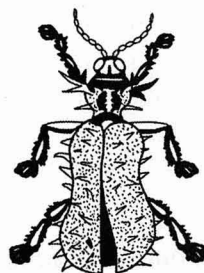


Fig. 1.16: Rice hispa

Leaf Roller/Folder

Caterpillars of this pest cause damage by folding the leaf blades into tubular structures and feeding on the green leaf tissues within these structures. Usually only one caterpillar is found within a fold. The larvae feed within this portion of the leaf causing typical white streaks by consuming all but the epidermis of the inside of the leaf, pupation occurs within the rolled portion.

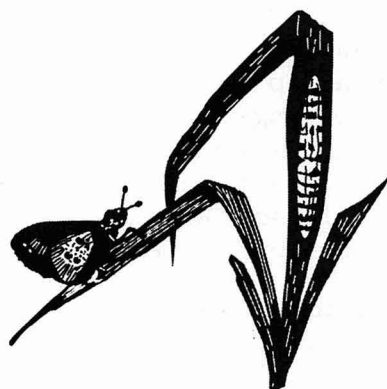


Fig. 1.17: Leaf roller

Control Measures

When the leaf damage reaches 10% (ETL), adopt the following control measures:

- **Mechanical Control:** The mechanical control of leaf folder can be done only before flowering by passing the 20–30 m long coir/jute rope, forwards and then backwards, both ways while touching the crop canopy. While passing the rope, ensure that water must be standing in the crop.
- **Chemical Control:** Spray the crop with 50 ml Fame 480 SC (flubendiamide) or 425 g of Mortar 75 SG (cartap hydrochloride) or 2.5 litre of Coroban/Durmet/Force 20 EC (chlorpyrifos) in 750–800 litres of water per hectare.

Swarming Caterpillar

This pest causes severe damage in nursery beds. Newly hatched larvae cut leaves cause plants to look sickly with withered tips. Older larvae feed voraciously and cause almost complete defoliation. These larvae migrate from fields and do damage at night.

Control Measures

In case of moderate to severe damage, spray 2 liters of Ekalux 25 EC (quinalphos) or 2.5 litre of chlorpyrifos 20EC in 750–800 litres of water per hectare with a manually operated sprayer. Repeat the spraying if the attack persists.

Army Worm or Earhead Cutting Caterpillar

The caterpillars are greenish-brown in colour with a pair of prominent dorsolateral stripes on the body. Larvae feed voraciously on leaves, resulting in skeletonising of leaf blades. They have a climbing habit and cut panicles from base and do damage at night. The insect migrates from one field to another.

Control Measures

For effective control of this pest, spray one litre of Ekalux (quinalphos) in 500 litres of water per hectare with hand-operated knapsack sprayer. For better effectiveness of the insecticide, spraying should be done in the evening when armyworm larvae are more active.

Gundhi Bug

Both nymphs and adults cause damage by sucking the plant sap and particularly the milky juice of the developing grains in early morning hours or at dusk. The grains are then either empty or partly filled and shrivelled. This pest is popularly known as Gundhi bug because it produces unpleasant smell when touched or disturbed.

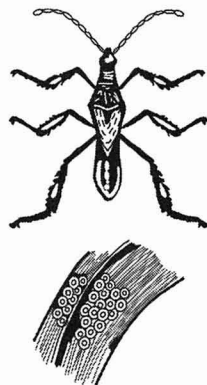


Fig. 1.18. Gundhi bug

Control Measures

In case there are five or more insects per meter row length, apply 5% melathion dust @ 20–25 kg/ha.

Mole Cricket

This is a problem on raised nursery beds and in upland fields. Flooded rice becomes infested only when water is removed from the field. The adults feed on the young roots and basal portions of the plant below the ground. They may kill the plant by cutting at the base.

Control Measures

In case of moderate to severe damage, spray 2 liters of Ekalux 25 EC (quinalphos) in 750–800 litres of water per hectare.

Green Leaf Hopper

Generally, leaf hoppers feed on leaves and upper parts of plants by sucking cell sap. It also transmits tungro virus disease. The disease is characterised by slight stunting and reduced tillering. Young leaves are often mottled with pale-green to whitish stripes. Infected plants bear a few light spikelets.

Control Measures

1. In case of moderate to severe damage, spray 125 ml imidachloprid in 750–800 litres of water per hectare.
2. Grow resistant varieties as recommended for your area in Table 1.2.

Plant Hoppers (White Backed and Brown Plant hoppers)

These are of two types—white backed plant hopper and brown plant hopper. White backed plant hopper is common in the early crop season (July–August), whereas brown plant hopper appears during later part of the crop season (October–November). Both the plant hoppers cause severe damage by sucking plant sap. This serious damage is called ‘hopper burn’. A large number of plant hoppers are confined to basal portion of the plant. Due to sucking plant sap by these pest, there is yellowing of plants followed by rapid drying. Brown plant hopper in addition to causing direct damage also transmits ‘grassy stunt virus disease’. The disease is characterised by narrow, erect leaves which are usually yellow to yellowish green with numerous dark spots. If the plants produces panicles, they are small and have dark brown unfilled grain.

Control Measures

1. About one month after transplanting, a few plants in the field should be slightly tilted and tapped 2 or 3 times at the base at weekly interval. If minimum 5 plant hoppers per hill (economic threshold level, ETL) are seen floating in the water, only then the crop should be treated with insecticides. The plant hoppers can be controlled by spraying 225 ml triflumezopyrim 10 SC or 300 g pymetrozine 50 EC (Chess 50 WG) or 100 ml imidacloprid 200 SL (Confidor/Crocodile) or 2000 ml quinalphos 25 EC (Ekalux/Quinguard/Quinalmass) in 750–800 litres of water per hectare. Repeat the spray, if necessary. For better effectiveness, use knapsack sprayer while directing its spray towards the base of the plants. If the damage is noticed at hopper burn stage, treat the affected spots along with their 3–4 metres periphery immediately as these spots harbour high population of the insect.
2. Spray 235 ml Pexalon 10 SC per hectare for the management of plant hoppers.
3. Grow resistant varieties as per recommendation of the area.

HARVESTING AND THRESHING

Harvest the crop as soon as it matures. If delayed, grain may be lost due to damage by rats, birds, insects, shattering and lodging. Timely harvesting ensures good grain quality, consumer acceptance, since the grain is less likely to break when milled. The right stage for harvesting is when about 80% panicles have about 80% ripened spikelets. At the time of harvest the upper portion of the spikelets should be straw coloured. The grain will contain about 20% of moisture. The crop is generally cut with serrate edged sickles by hand. The plants should be cut quite close to the ground and left in the field for a few days to dry. Later on, they should be collected in bundles and stacked for threshing.

Threshing of rice on small farms is still a major problem. The most common methods of threshing are trampling by bullocks, rubbing with bare human

feed (in hills) or lifting the bundles and striking them on the raised wooden platform. On big farms pedal threshers or power driven stationary threshers are also in use.

YIELD

A well-managed crop of mid-late duration (135–150 days) paddy, yields about 60–70 quintals paddy/ha. Short duration varieties yield about 45–55 quintals of paddy/ha. Hybrid rice yields about 60–70 quintals of paddy/ha. Freshly threshed rice spoils rapidly because of high moisture content in the grain. They should be dried well in sun before storage.

Wheat

(*Triticum aestivum* L.)

Wheat is the world's most widely cultivated food crop. It is eaten in various forms by more than 1000 million human beings in the world. In India it is second important staple food crop, rice being the first. In areas where wheat is the staple cereal food, it is eaten in the form of 'chapatis'. In areas where rice is the staple cereal food wheat is eaten in the form of 'puris' or in the form of 'upma' (cooked from suji or rawa). In addition to this, wheat is also consumed in various other preparations such as 'dalia', 'halwa', 'sweet meals', etc. In most of the urban areas in the country the use of backed leavened bread, flakes, cakes, biscuits, etc. is increasing at a fast rate.

Besides staple food for human beings, wheat straw is a good source of feed for a large population of cattle in our country.

Wheat compares well with other important cereals in its nutritive value. It contains more protein than other cereals. Wheat has a relatively high content of niacin and thiamine. Wheat proteins are of special significance. Besides, their significance in nutrition, they are principally concerned in providing the characteristic substance 'gluten' which is very essential for bakers. In bakery gluten provides the structural framework for the familiar spongy, cellular texture of bread and other baked products. Flours of other cereals lacking gluten are, therefore, not good for bread making.

ORIGIN AND HISTORY

Wheat has been grown since prehistoric times, so long ago that the origin of wheat is still a matter of speculation. All available records and evidence reveal its origin from the North East, where wild forms of wheat were cultivated as early as 10,000 to 15,000 BC. The tetraploid and hexaploid species of wheat originated from the wild diploid species by mutations and hybridisation resulting in a wide range of adaptability in the modern wheat, the most important cultivated wheat species are *Triticum aestivum* (hexaploid) and *Triticum durum* (tetraploid).

The spread of wheat has also not been clearly established. Ancient Chinese records indicate its cultivation in China around 2700 BC. In the Indian context, Mohenjodaro excavations show that wheat was used throughout the Harappan period from 2300 to 1750 BC. This wheat was hexaploid and appears to have originated in the North-Western sector of the Indian subcontinent.

AREA AND DISTRIBUTION

Wheat is the world's leading cereal crop cultivated over an area of about 216 million hectares with a production of 765.8 million tonnes of grain with productivity of 3547 kg/ha during 2019 (FAOSTAT).

Maximum area under wheat is in India followed by Russian Federation, China, USA, Kazakhstan, Australia and Canada. However, China stands first in terms of production followed by India, Russian Federation, USA and France.

In India, wheat is the main cereal crop covering 31.4 million hectare with production of 107.9 million tons with average productivity of 3440 kg/ha during 2019-20 (<https://www.indiastatagri.com>). In respect of area and production, wheat occupies second position, being exceeded by rice. Uttar Pradesh, Madhya Pradesh, Punjab, Rajasthan, Haryana, Bihar, Maharashtra and Gujarat are major wheat growing states in the country. Though the maximum acreage and production of wheat is in Uttar Pradesh but Punjab has the highest average productivity (5003 kg/ha) followed by Haryana (4687 kg/ha). India accounts about 14 percent of total wheat production of the world.

CLASSIFICATION

Wheat is an annual plant of *Poaceae* family (formerly called *Gramineae*). It belongs to genus *Triticum*. Although as many as 18 species of wheat have been described and recognised by Percival (1921), only a few are of importance in agriculture. The following is the classification on the basis of chromosomal number:

<i>Einkorn series (diploid)</i>	<i>Chromosome No.</i>
1. <i>Triticum aegiloploids</i>	7
2. <i>Triticum monacocum</i>	7
<i>Einkorn series (tetraploid)</i>	
1. <i>Triticum dicoccoides</i>	14
2. <i>Triticum timopheevi</i>	14
3. <i>Triticum persicum</i>	14
4. <i>Triticum polonicum</i>	14
5. <i>Triticum turgidum</i>	14
6. <i>Triticum orientale</i>	14
7. <i>Triticum durum</i>	14
8. <i>Triticum dicocum</i>	14
<i>Dinkale series (hexaploid)</i>	
1. <i>Triticum spelta</i>	21
2. <i>Triticum macha</i>	21
3. <i>Triticum aestivum</i> or <i>vulgare</i>	21

In India only three species of wheat, namely *Triticum aestivum* (common bread wheat), *Triticum durum* (macaroni or durum wheat) and *Triticum dicocum* (emmer wheat), are economically important. The bread wheat (*Triticum aestivum*) is the most important species accounting to a little over 87% of the total wheat production of India followed by the durum wheat (about 12%)

and dicoccum wheat (about 1%). The common wheat (*Triticum aestivum*) which is good for chapati making and bakery products, is grown in whole of North India and also in Central and South India. The durum wheat which is good for 'suff', 'semya', 'sphagetti' and 'macaroni' is grown only in Central and South India and that too under rainfed conditions. The dicoccum wheat is grown only on limited acreage in Tamil Nadu, Andhra Pradesh, Maharashtra and Gujarat. It is good for the South Indian dish 'Uppumav'.

BOTANICAL DESCRIPTION

Wheat plant can be divided in two distinct parts, *viz.* root system and shoot system.

Root System

Primary Root System or Temporary Root System

It forms at the time of seed germination and absorbs nutrients for the young seedling. It arises at the depth where the seed is planted. As plant growth progresses, the primary root system usually dies and is replaced by the more permanent secondary root system.

Secondary Root System

It arises at a point above the primary root system as the principal organ of absorption as the young wheat seedling progresses to maturity. It is the root system which arises near the soil surface at the time of crown root initiation stage (usually 21–25 days after sowing in Mexican dwarf wheat). It is a permanent root system.

Shoot System

Collectively applies to all plant visible above the ground. It is composed of stems, leaves and inflorescence (flowering and fruiting clusters). A stem and inflorescence may be called a culm (Fig. 2.1).

Stem

The stem of wheat plant is round or cylindrical. In most varieties of the bread wheat the stems are hollow, except at the nodes where they are solid, but in a few varieties of Macaroni wheats the internodes are completely filled with soft pith.

Leaves

Leaf consists of four parts:

- (a) *Leaf sheath*: It is the basal part of the leaf. It encircles the culm

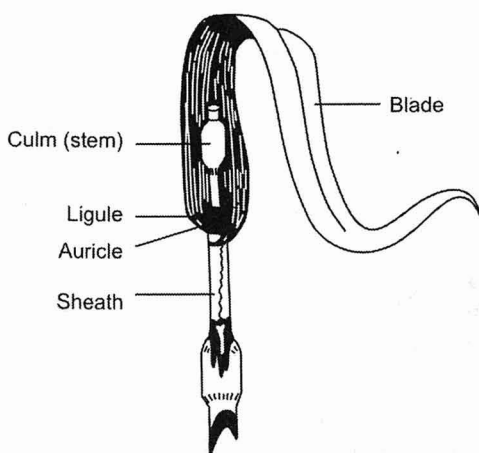


Fig. 2.1: Parts of wheat culm

(stem) and protects the growing point and axillary buds from the weather, and provides some support to stem.

(b) *Leaf blade*: The flattened, parallel veined portion of the leaf.

(c) *Ligule*: A membranous or cartilaginous fringe at the junction of the sheath and the blade on the side of the leaf next to culm. The continuation of the sheath through the collar is known as the ligule.

(d) *Auricle*: Lobes of the leaf blade which extend downward on each side at the junction of the blade and sheath. These are horn-like or claw-like appendages projecting from the collar of the leaf.

Inflorescence

The flowering portion of the wheat plant is called 'ear' or 'head', but in botanical language it is a spike. Spikelets are systematically arranged and are distributed along a common axis. The central zigzag axis is the rachis. The spikelets are borne on alternate sides of the rachis, which gives it a zigzag appearance.

Spikelet: Spikelet is composed of flowers called florets. The number of florets in a spikelet may vary from 1 to 5. The florets in each spikelet are enclosed by two glumes.

Florets: The outer covering of a floret is made up of a lemma and a palea. The lemma enfolds the palea near their attachment point. If an awn is present, it is attached to the lemma (Fig. 2.2).

Kernel: Wheat has a caryopsis type of fruit. The typical wheat kernel is from 3–10 mm in length and from 3–5 mm in diameter. The composition of a wheat kernel is:

1. The germ (the embryo, consisting of plumule, scutellum, radicle and hypocotyl) comprises about 2.5%. It is high in proteins and fats.
2. The bran (pericarp, testa, nucellus, and aleurone layer) comprises as much as 14%. It is a by-product of milling and is used in dairy and poultry feeds. Small amounts are used in breakfast cereal.
3. The starchy endosperm (the storage part of the caryopsis that develops from the union of polar nuclei with the endosperm nucleus) comprises from 83 to 87%.

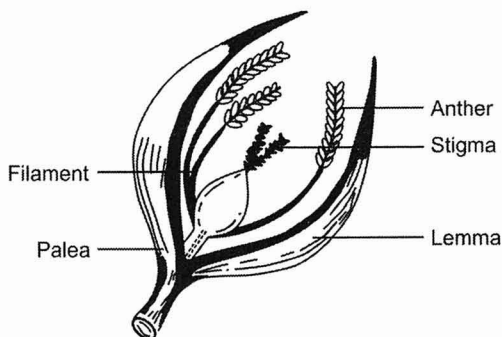


Fig. 2.2: Parts of wheat floret

CLIMATIC REQUIREMENTS

Wheat crop has wide adaptability. It can be grown not only in the tropical and subtropical zones but also in the temperate zone and the cold tracts of the far north, beyond even the 60° north latitude. Wheat can tolerate severe cold and snow and resume growth with the setting in of warm weather in spring. It can be cultivated from sea level to as high as 3300 m.

The best wheats are produced in areas favoured with cool, moist weather during the major portion of the growing period followed by dry, warm weather to enable the grain to ripen properly. The optimum temperature range for ideal germination of wheat seed is 20 to 25°C though the seeds can germinate in the temperature range 3.5–35°C. Rains just after sowing hamper germination and encourage seedling blight. Areas with a warm and damp climate are not suited for wheat growing.

During the heading and flowering stages, excessively high or low temperatures and drought are harmful to wheat. Cloudy weather, with high humidity and low temperatures is conducive for rust attack. Wheat plant requires about 14–15°C optimum average temperature at the time of ripening. The temperature conditions at the time of grain filling and development are very crucial for yield. Temperatures above 25°C during this period tend to depress grain weight. When temperatures are high, too much energy is lost through the process of transpiration by the plants and the reduced residual energy results in poorer grain formation and lower yields. Wheat is mainly a *Rabi* (winter) season crop in India.

SOIL

Wheat is grown in a variety of soils of India. Soils with a clay loam or loam texture, good structure and moderate water holding capacity are ideal for wheat cultivation. Care should be taken to avoid very porous and excessively drained soils. Soil should be neutral in its reaction. Heavy soils with good drainage are suitable for wheat cultivation under dry conditions. These soils absorb and retain rain water well. Heavy soils with poor structure and poor drainage are not suitable as wheat is sensitive to water logging. Wheat can be successfully grown on lighter soils provided their water and nutrient holding capacities are improved.

In India, the wheat growing areas can be mainly divided into five soil divisions, *viz.* (1) the Gangetic alluvium of Uttar Pradesh and Bihar, (2) the Indus alluvium of Punjab and Haryana, (3) the black soil regions of central and southern India comprising Madhya Pradesh and parts of Maharashtra and Karnataka, (4) the hilly regions of the Himalaya and elsewhere, and (5) the desert soils of Rajasthan.

VARIETIES

A number of promising wheat varieties have been released for cultivation under different production zones. These are furnished in Tables 2.1 to 2.3.

Varieties Development in India

Wheat breeding in India was first initiated in a systematic way at the Imperial Agricultural Research Institute, Pusa, Bihar in 1905. The emphasis during earlier days was given to varietal development through pureline selection in indigenous material. This led to the development of wheat varieties Pusa 4,

Table 2.1: Zone-wise wheat varieties released/notified during last 20 years (2000 onwards)

Name of variety	Institute/SAU	Year of release	Yield (t/ha)		Special features
			Av.	Pot.	
Varieties suitable for irrigated, timely sown conditions of NWPZ					
WB 2	IIWBR, Karnal	2017	5.16	5.89	Zinc (42.0 ppm) and iron (40.0 ppm) rich wheat variety
PBW 723 (Unnat PBW 343)	PAU, Ludhiana	2017	4.92	6.32	Resistant to yellow and brown rust
HPBW 01 (PBW 1 Zn)	PAU, Ludhiana	2017	5.17	6.48	Zinc (40.6 ppm) rich wheat variety resistant to yellow and brown rust
HD 3086 (Pusa Gautami)	IARI, New Delhi	2014	5.46	7.11	Resistant to yellow and brown rust
DBW 88	IIWBR, Karnal	2014	5.42	6.99	Resistant to yellow and brown rust
WH 1105	CCSHAU, Hisar	2013	5.25	7.16	Resistant to yellow and brown rust, leaf blight and powdery mildew
HD 2967	IARI, New Delhi	2011	5.04	6.60	Wider adaptability and resistant to yellow rust
DPW 621-50 (PBW 621 and DBW 50)	IIWBR, Karnal and PAU, Ludhiana	2011	5.17	6.98	Resistant to yellow rust
PBW 550	PAU, Ludhiana	2008	4.77	6.24	High degree of resistant to yellow and brown rust
DBW 17	IIWBR, Karnal	2007	4.84	6.30	Tolerant to terminal heat and resistant to yellow rust
PBW 502	PAU, Ludhiana	2004	4.62	6.00	Resistant to yellow rust, brown rust and karnal bunt
Varieties suitable for irrigated, late sown conditions of NWPZ					
DBW 173	IIWBR, Karnal	2018	4.72	5.70	Tolerant to terminal heat, resistant to yellow rust and brown rust
DBW 90	IIWBR, Karnal	2014	4.27	6.66	Adult plant resistant to yellow and brown rust
WH 1124	CCSHAU, Hisar	2014	4.27	5.61	Resistant to yellow rust and brown rust and tolerant to terminal heat
HD 3059 (Pusa Pachhetti)	IARI, New Delhi	2013	4.25	5.94	Resistance to all three rusts and also to black rust race Ug99
DBW 71	IIWBR, Karnal	2013	4.27	6.89	Resistant to yellow rust
PBW 590	PAU, Ludhiana	2009	4.22	7.32	High degree of resistant against yellow and brown rust

(Contd.)

Name of variety	Institute/SAU	Year of release	Yield (t/ha)		Special features
			Av.	Pot.	
WH 1021	CCSHAU, Hisar	2008	3.90	6.25	Resistant to all the three rusts
DBW 16	IIWBR, Karnal	2006	3.82	5.64	Resistant to yellow and brown rust
Varieties suitable for rainfed, timely sown conditions of NWPZ					
PBW 660	PAU, Ludhiana	2016	3.53	4.93	High degree of resistance to yellow rust, brown rust and good for chapatti making quality (Score: 7.96)
PBW 644	PAU, Ludhiana	2012	3.14	4.48	High degree of resistance to yellow rust
WH 1080	CCSHAU, Hisar	2011	3.08	4.44	High protein content (12.5%)
PBW 396	PAU, Ludhiana	2000	3.35	3.94	Resistant to yellow and brown rust
Varieties suitable for restricted irrigation, timely sown conditions of NWPZ					
WH 1142	CCSHAU, Hisar	2015	4.81	6.25	Tolerance to drought and lodging
HD 3043	IARI, New Delhi	2012	4.28	5.02	Adult plant resistance to yellow and brown rust
Varieties suitable for irrigated, timely sown conditions of NEPZ					
K 1006	CSAUAT, Kanpur	2014	4.70	6.54	Tolerance to leaf blight, loose smut and powdery mildew
NW 5054	NDUAT, Faizabad	2014	4.70	6.42	Resistance to foliar blight and brown rust
HD 2967	IARI, New Delhi	2014	4.50	6.50	Wider adaptability
DBW 39	IIWBR, Karnal	2010	4.46	6.47	Resistance to black rust, brown rust and tolerant to leaf blight
RAJ 4120	RARI, Durgapura	2009	4.70	6.63	Resistance to all the three rusts and tolerant to leaf blight
CBW 38	IIWBR, Karnal	2009	4.44	6.53	Resistance to yellow rust, brown rust and tolerant to leaf blight
K 0307 (Shatabdi)	CSAUAT, Kanpur	2007	4.56	6.50	Tolerance to terminal heat stress
HD 2824 (Poorva)	IARI, New Delhi	2004	4.57	7.0	Resistance to brown rust and tolerant to leaf blight
HD 2733	IARI, New Delhi	2001	4.81	7.15	Resistance to brown rust and tolerant to leaf blight
PBW 443	PAU, Ludhiana	2000	4.68	5.27	Resistance to brown rust

(Contd.)

Name of variety	Institute/SAU	Year of release	Yield (t/ha)		Special features
			Avg.	Pot.	
Varieties suitable for irrigated, late sown conditions of NEPZ					
HD 3118 (Pusa Vatsala)	IARI, New Delhi	2015	4.17	6.60	High degree of resistance to yellow and brown rust
DBW 107	IIWBR, Karnal	2015	4.13	6.87	Resistance to brown rust and tolerant to terminal heat
HD 2985 (Pusa Basant)	IARI, New Delhi	2011	3.77	5.14	High level of resistance against leaf blight, foot rot and adult plant resistance against brown rust
HI 1563 (Pusa Prachi)	IARI RS, Indore	2011	3.76	5.17	Resistance of all pathogens of the three rusts at seedling stage
DBW 14	IIWBR, Karnal	2003	4.27	6.39	Tolerant to leaf blight
NW 2036	NDUAT, Faizabad	2003	4.25	6.62	Resistance to brown rust and tolerant to leaf blight
HW 2045 (Kaushambi)	IARI RS, Wellington	2002	3.37	4.19	Early maturing variety, tolerant to terminal heat
Varieties suitable for rainfed/restricted irrigation, timely sown conditions of NEPZ					
HI 1612	IARI RS, Indore	2018	—	—	Yield gain at one irrigation (32.4%) and two irrigation (52.4%) over no irrigation. High degree of resistance to yellow and brown rust
K 1317	CSAUAT, Kanpur	2018	3.01	3.86	Resistant to brown rust and leaf blight. Good chapati quality (Score: 8.05)
HD 3171	IARI, New Delhi	2017	2.80	4.63	High degree of resistance to yellow, brown and black rusts, higher iron content (47.1 ppm)
HD 2888	IARI, New Delhi	2006	2.25	3.83	High degree of resistance to brown rust, black rust and having high flour recovery
MACS 6145	ARI, Pune	2005	2.55	3.70	Highly resistant to brown rust
Varieties suitable for irrigated, timely sown conditions of Central Zone					
HI 1544 (Purna)	IARI RS, Indore	2008	5.14	6.82	Early maturing, field resistance to brown rust, black rust and having pubescent glume
GW 366	JAU, Junagarh	2007	5.17	7.79	Resistant to brown and black rust
GW 322	RARS, Vijapur	2002	4.47	6.63	High degree of resistance to black rust, brown rust and tolerant to terminal heat

(Contd.)

Name of variety	Institute/SAU	Year of release	Yield (t/ha)		Special features
			Av.	Pot.	
Varieties suitable for irrigated, late sown conditions of Central Zone					
Raj 4238	RARI, Durgapura	2016	4.55	6.28	Good for chapatti quality
MP 3336	JNKVV, Jabalpur	2013	4.47	6.44	Resistant to brown rust and black rust
MP 1203	JNKVV RS, Powarkhera	2009	4.12	5.96	High protein content (13.5%)
HD 2932	IARI, New Delhi	2008	4.20	5.78	Resistant to brown rust and high zinc content
HD 2864 (Urja)	IARI, New Delhi	2005	4.17	5.15	Highly resistant to brown rust, foot rot and tolerant to black rust
MP 4010	RVSKVV, Gwalior	2003	4.01	5.36	Resistance to black rust, brown rust and tolerant to terminal heat
Varieties suitable for rainfed/restricted irrigated, timely sown conditions of Central Zone					
DBW 110	IIWBR, Karnal	2015	3.90	5.05	Resistance to brown rust
MP 3288	JNKVV, Jabalpur	2011	2.32	4.21	Tolerant to major diseases
MP 3173	JNKVV, Jabalpur	2009	2.57	4.60	Tolerant to drought
HI 1531 (Harshita)	IARI RS, Indore	2006	2.40	3.98	Tolerant to drought and resistant to brown rust
HI 1500 (Amrita)	IARI RS, Indore	2003	1.60	3.00	Resistance to brown rust, black rust and good quality chapatti quality
Varieties suitable for irrigated, timely sown conditions of Peninsular Zone					
DBW 168	IIWBR, Karnal	2018	4.75	7.01	Very good for chapatti (8.15) and for biscuit quality, soft grains (36), resistance to brown and black rust
MACS 6478	ARI, Pune	2014	4.50	6.57	Good for chapatti quality, resistant to black and brown rust
UAS 304	UAS, Dharwad	2013	4.68	5.99	—
MACS 6222	ARI, Pune	2010	4.77	6.09	Resistant to black and brown rust
NIJAW 917 (Tapovan)	MPKV RS, Niphad	2006	4.66	6.25	Resistant to black and brown rust
RAJ 4037	RARI, Durgapura	2004	4.09	5.93	Resistant to black and brown rust
GW 322	RARS, Vijapur	2002	4.17	6.18	Resistant to black rust, brown rust and tolerant to terminal heat

(Contd.)

Name of variety	Institute/SAU	Year of release	Yield (t/ha)		Special features
			Av.	Pot.	
Varieties suitable for irrigated, late sown conditions of Peninsular Zone					
HD 3090 (Pusa Amulya)	IARI, New Delhi	2014	4.14	6.31	Resistant to brown and black rust
AKAW 4627	PDKV, Akola	2012	4.28	6.09	Resistant to brown and black rust
HD 2932	IARI, New Delhi	2008	4.33	5.36	Resistant to brown and black rust
RAJ 4083	RARI, Durgapura	2007	4.15	5.66	Resistant to brown and black rust
HD 2833	IARI, New Delhi	2006	3.89	5.93	Excellent chapatti quality and adult plant resistance to brown and black rust
HUW 510 (Malviya 510)	BHU, Varanasi	2001	3.54	4.73	Resistant to brown and black rust
Varieties suitable for rainfed, timely sown conditions of Peninsular Zone					
UAS 375	UAS, Dharwad	2018	2.14	2.91	Resistance to brown and black rust
UAS 347	UAS, Dharwad	2015	1.84	2.46	Resistance to brown and black rust
HD 2781 (Aditya)	IARI, New Delhi	2002	1.58	2.36	Resistance to brown and black rust
K 9644 (Atal)	CSAUAT, Kanpur	2000	1.50	1.74	Resistance to brown and black rust, heat tolerant
Varieties suitable for rainfed/ restricted irrigation, timely sown conditions of Peninsular Zone					
HI 1605 (Pusa Ujala)	IARI RS, Indore	2017	2.90	4.40	Resistance to brown and black rust, excellent chapatti quality (8.04)
DBW 93	IIWBR, Karnal	2015	2.93	3.90	Resistance to black rust
NIAW 1415 (Netravati)	MPKV RS, Niphad	2011	1.95	3.62	—
HD 2987 (Pusa Bahar)	IARI, New Delhi	2011	1.75	3.22	High iron content and good for chapatti quality
Varieties suitable for rainfed and early sown conditions of NHZ					
HS 542 (Pusa Kiran)	IARI RS, Shimla	2015	3.29	4.93	Resistance to yellow rust, brown rust and good for chapatti quality
HPW 251	CSK HPKVV, Palampur	2008	3.44	4.95	Resistance to yellow rust, brown rust and loose smut
VL 829	VPKAS, Almora	2003	2.90	5.98	Dual purpose (green fodder + grain) variety

(Contd.)

Name of variety	Institute/SAU	Year of release	Yield (t/ha)		Special features
			Av.	Pot.	
SKW 196 (Shalimar Wheat-1)	SKUAST, Srinagar	2005	2.39	3.77	Resistant to yellow rust
TL 2969 (Triticale)	PAU, Ludhiana	2012	—	—	Resistance to yellow rust, brown rust, powdery mildew and karnal bunt
Varieties suitable for rainfed/irrigated, timely sown conditions of NHZ					
HS 562	IARI RS, Shimla	2016	3.60	5.88	Field resistance to brown and yellow rust
HPW 349	CSK HPKV, Palampur	2013	4.70	6.14	Resistance to yellow rust, brown rust and good for chapatti quality
HS 507 (Pusa Suketi)	IARI RS, Shimla	2011	2.66	5.43	Resistance to brown rust, yellow rust, leaf blight and karnal bunt
VL 907	VPKAS, Almora	2010	2.79	5.25	Resistance to yellow rust, brown rust and possess high iron content
HPW 184 (Chandrika)	CSK HPKV, Palampur	2005	3.36	4.08	Highly resistance to yellow and brown rust
VL 804	VPKAS, Almora	2002	2.57	4.31	Resistance to yellow and brown rust
Varieties suitable for rainfed/restricted irrigation, late sown conditions of NHZ					
HS 490 (Pusa Baker)	IARI RS, Shimla	2009	3.10	4.97	Good for biscuit making (spread factor 10.13)
VL 892	VPKAS, Almora	2008	3.76	5.90	Higher content of zinc, copper and manganese
HS 420 (Shivalik)	IARI RS, Shimla	2003	2.67	4.47	Resistance to yellow and brown rust
Varieties suitable for rainfed, timely sown conditions of higher altitude areas of NHZ					
VL 832	VPKAS, Almora	2004	2.62	3.52	Resistance to yellow rust, brown rust, hill bunt and loose smut
HS 375 (Himgiri)	IARI RS, Shimla	2003	2.66	4.98	Tolerance to flag smut and hill bunt

Av. = Average; Pot. = Potential; NWPZ = North Western Plain Zone; NEPZ = North Eastern Plain Zone; NHZ = North Hills Zone

Source: ICAR—Indian Institute of Wheat and Barley Research, Karnal

Table 2.2: Zone-wise Durum and Dicoicum wheat varieties released/notified during last 20 years

Name of variety	Institute/SAU	Year	Yield (t/ha)		Special features
			Av.	Pot.	
Durum varieties notified for irrigated, timely sown condition of NWPZ					
WHD 943	CCSHAU, Hisar	2011	4.80	6.39	Tolerant to Karnal bunt
PDW 314	PAU, Ludhiana	2010	5.03	7.12	High degree of resistance against leaf blight
PDW 291	PAU, Ludhiana	2005	4.76	5.80	Resistance to yellow rust, Karnal bunt and flag smut
Durum and Dicoicum varieties notified for irrigated, timely sown condition of Central Zone					
HI 8759 (Pusa Tejas)	IARI RS, Indore	2017	5.69	7.55	Zinc (42.8 ppm) and iron (42.1 ppm), protein (12.0%) rich durum wheat, good for pasta making, takes 117 days for maturity
HD 4728 (Pusa Malwi)	IARI, New Delhi	2016	5.42	7.51	Resistance to brown rust, black rust and lustrous grain
HI 8737 (Pusa Anmol)	IARI RS, Indore	2015	5.34	8.10	Resistance to brown rust, black rust, Karnal bunt and high yellow pigment content
HI 8713 (Pusa Mangal)	IARI RS, Indore	2013	5.23	6.82	Resistance to brown rust, black rust and high yellow pigment content
MPO 1215	JNKVV RS, Powerkheda	2010	4.86	6.53	Field resistance to brown rust, black rust and good for pasta making
DDK 1029 (Dicoicum)	UAS, Dharwad	2007	4.09	5.99	Profuse tillering, dwarf growth habit, heat tolerance
HI 8627 (Malva Kirti)	IARI RS, Indore	2007	2.01	3.88	Resistance to brown and black rust
HD 4672 (Malva Ratna)	IARI, New Delhi	2000	1.51	3.42	Resistance to brown rust
Durum and Dicoicum varieties notified for rainfed, restricted irrigation, timely sown condition of Central Zone					
HI 8627 (Malva Kirti)	IARI RS, Indore	2007	2.01	3.88	Resistance to brown and black rust
HD 4672 (Malva Ratna)	IARI, New Delhi	2000	1.51	3.42	Resistance to brown rust
Durum and Dicoicum varieties notified for irrigated, timely sown condition of Peninsular Zone					
MACS 2971	ARI, Pune	2009	5.02	6.20	Resistance to black and brown rust
DDK 1029	UAS, Dharwad	2007	5.02	6.20	Profuse tillering, dwarf growth habit
DDK 1025	UAS, Dharwad	2006	3.80	4.97	Higher test weight

(Contd.)

Name of variety	Institute/SAU	Year	Yield (t/ha)		Special features
			Av.	Pot.	
Durum and Dicoccum varieties notified for irrigated, timely sown condition of Peninsular Zone					
MACS 3949	ARI, Pune	2017	4.40	6.43	Resistance to stem and leaf rusts, good pasta quality (overall acceptability 7.25)
WHD 948	CCSHAU, Hisar	2014	4.65	6.95	Resistance to Karnal bunt and loose smut, good for pasta quality
UAS 428	UAS, Dharwad	2012	4.80	5.88	Resistance to brown and black rust
UAS 415	UAS, Dharwad	2009	4.96	6.18	Resistance to all three rusts, foliar blight, powdery mildew
HI 8663 (Poshan)	IARI RS, Indore	2008	4.55	7.15	High beta carotene (6.5 ppm) content, suitable for semolina recovery
Durum varieties notified for rainfed, timely sown condition of Peninsular Zone					
HI 8777	IARI RS, Indore	2018	1.85	2.88	Resistance to leaf rust and field resistance to stem rust, higher level of protein (14.3%), zinc (43.6 ppm) and iron (48.7 ppm) content
MACS 4028	ARI, Pune	2018	1.93	2.87	High degree of resistance against stem and leaf rust, early maturing (102 days), higher protein content (14.7%)
UAS 446	UAS, Dharwad	2015	1.83	2.44	Resistance to brown and black rust and high protein content
Varieties notified/released for saline and alkaline soil conditions of all zones					
KRL 210	CSSRI, Karnal	2012	3.37	4.93	Resistance to yellow rust and Karnal bunt
KRL 213	CSSRI, Karnal	2011	3.25	4.39	Saline and alkaline soils, resistance to yellow rust and Karnal bunt
KRL 19	CSSRI, Karnal	2000	3.04	4.64	Also suitable for water logging area and tolerant to yellow rust and brown rust

Av. = Average; Pot. = Potential

Source: ICAR—Indian Institute of Wheat and Barley Research, Karnal

Table 2.3: Wheat varieties released for different wheat growing states

State	Name of varieties
Bihar	BRW 3708 (Sabour Samriddhi), BRW 3723 (Sabour Nirjal), BRW 934 (Sabour Shreshtha), BR 104GJW
Chhattisgarh	CG 1013, CG 5016, CG 5016 (Ratan)
Delhi	HD 3117, HD CSW 18, HD 2894, HD 2851, Duram: HD 4713
Gujarat	GJW 463, GW 451, GW 496, GW 503, GW 40, J 24, GW 11, GW 405, GW 18, Duram: GW 2, A 28, GDW 1255, GW 1139
Himachal Pradesh	DH 114, HPW 155, Saptdhara, HPW 147, HPW 89, RAJ 3777
Haryana	WH 711, WHD 912, WH 1025, WH 533, Sonak
Jammu & Kashmir	Mansarovar, SWL 8, Kailash, Shalimar Wheat 2, RSP 561
Karnataka	UAS 334, DWR 16, Pusa Lerma, Duram: DWR 137, Bijaga yellow, Bijaga red, DWR 1006, DWR 185
Madhya Pradesh	MP 3382, MP 1201, MP 1142, HI 1479, HI 1454, Tawa 267, Narmada 112, Narmada 195, Narmada 4, MP 3211, JW 3020, MP 4106, MP 1202, HI 1418, Duram: MPO 1106, Narmada 215, MPO 1255
Maharashtra	AKAW 3722,, WSM 1472, NIAW 301, PBN 51, NI 5643, Ajanta, AKAW 4210-6, NIAW 1994, NIAW 34, Duram: NIDW 295, MACS 3125, MACS 2694, NIDW 15, NI 5749
Odisha	OW 6 (Sagarika), Utkalika
Punjab	Timely sown: Unnat PBW 343, Unnat PBW 550, PBW 1 Zn, PBW 725, PBW 677, PBW 120, PBW 12, PBW 54, WL 1562, WG 377, WG 357, PV 18, PBW 658, PBW 509, PBW 138, PBW 527, HD 3086, WH 1105, HD 2967 Late sown: PBW 621 PBW 752 PBW 658 Duram: PDW 274, WHD 943 PDW 291 Rainfed: PBW 660, PBW 644
Rajasthan	RAJ 4079, RAJ 1114, Chambal 65, Durgapur A65, Ganga Sonaheri, RS 31-1, RAJ 3777, RAJ 821, CCNNRV 01 (Cereal cyst nematode resistant), Duram: RAJ 6560
Tamil Nadu	CoW 2 (HW 1095), CoW 3 (HW 5207), CoW1
Uttar Pradesh	Timely sown, irrigated condition: K 0607 (Mamta), K 0402 (Mahi), NW 1067, K 9006 (Ujiyar), UP 2121, UP 2003, KML 7406 (Bithoor), UP 301, NP 401 (Bundelkhand area) Timely sown irrigated condition of Western UP: UP 2382, UP 368, UP 310, UP 319, HD 1949 (Moti) Timely sown rainfed for Eastern UP: K 852 Timely sown rainfed condition of Eastern UP: NW 4018, K 9351 (Mandakini), UP 2113, K 72, K 78, K 65, HUW 669 (Malviya), K 68, K 816 Late sown irrigated condition of whole UP: SHIATS-W6, K 9533 (Naina), K 7903 (Halna), K 9162 (Gangotri) Saline soil for whole UP: KRL 283, K 8434 (Prasad)
Uttarakhand	Plains: UP 2784, UP 2628, UP 2554, UP 2382, UP 2526, UP 2565 Hills: UP 2572, VL 802, VL 719, VL 401, VL 404, VL 953 (suitable for organic farming)
West Bengal	BW 1008 (Teesta)

Source: Gupta et al, 2018

Pusa 6 and Pusa 12, which were further used in hybridization programme. Later, wheat improvement work was initiated at Lyallpur, Kanpur, Sabour, Powarkheda, Niphad and Pune resulting in many outstanding wheat varieties like PbC518, PbC591, C273, C281 and C286. In 1935, work on resistance breeding was initiated which resulted in the development of rust resistant varieties like NP 783 and NP 784 (resistant to brown rust); NP 785 and NP 786 (resistant to

HD 2967: Most popular variety of wheat

HD 2967 is a double dwarf variety developed by ICAR-IARI, New Delhi and released in 2011 for north-western and eastern plains. It has profuse tillering, ears are medium dense and tapering in shape with white glumes. Its grains are amber, medium bold, hard and lustrous having excellent chapatti making quality, high protein content (12–13.5%) and preferred by millers because of high flour recovery. It is resistant to brown rust, moderately resistant to yellow rust, less susceptible to Karnal bunt and loose smut diseases.

HD 2967 variety is well adapted to north-western plain zone (NWPZ) and eastern plain zone (NEPZ) of India for timely sown irrigated situation with average yield of 5.2 t/ha (achieved maximum 8.5 t/ha at farmers fields) in north western plains and average yield of 4.4 t/ha (achieved maximum 7.2 t/ha at farmers fields) in eastern plains.

HD 2967 has given farmers an appropriate substitute to PBW 343, a popular variety developed by PAU, Ludhiana, which had come under severe attack of yellow rust and farmers were not ready to stop growing it. Finally, the agriculture department had stopped providing its seed as it had expired its shelf life and due to the severe attack of yellow rust on it.

The demand of breeder seed of HD 2967 is very high from different parts of wheat growing areas. During four years (2013-14 to 2016-17), more than 13315 Q breeder seed of this variety was produced, highest ever breeder seed production for any single wheat variety during last four years, speaks volume about its popularity. It is estimated that this variety covered more than 11.5 million hectare area during 2016-17 producing about 39 million tonnes of wheat worth more than Rs. 69000 crores.

Source: ICAR-Indian Agricultural Research Institute, Pusa, New Delhi.



Fig. 2.3: Wheat variety HD 2967 (Courtesy: ICAR-IIWBR, Karnal) (see Colour Plate 2)



Fig. 2.4: Wheat variety HD 3086 (Courtesy: ICAR-IIWBR, Karnal) (see Colour Plate 2)

all races of yellow rust); NP 789 and NP 790 (resistant to black rust). Later NP 809 resistant to all the three rusts and loose smut was developed by Dr BP Pal and Dr KC Mehta.

The varietal development programme got an impetus with the establishment of the All India Coordinated Wheat Improvement Project (AICWIP) at IARI, New Delhi, in 1965. It was just a matter of coincidence that the introduction of

semi-dwarf genotypes from Mexico and the establishment of AICWIP took place simultaneously. The massive hybridization work involving dwarf wheat genotypes led to the development of many high yielding and disease resistant wheat varieties in India which ushered in the green revolution in India. Four wheat varieties, namely Kalyansona, Sharbati Sonora, Sonalika and Chotti Lerma, were released for almost all the zone way back in 1969. Similarly, C306, a tall variety developed by CCSHAU, Hisar, for rainfed cultivation in NWPZ during early sixties is still preferred by consumers because of its chapatti quality and other traits.

Later, ICAR—Indian Institute of Wheat and Barley Research Institute located at Karnal (Haryana) was entrusted as the nodal centre for wheat research in India and is bestowed to function as the coordinating unit for organising multi-location research and evaluation/testing schedules for new genotypes of wheat under All India Coordinated Research Project on Wheat and Barley. Up to 2018, total 448 wheat varieties (378 are bread wheat, 59 durum, 7 diccicum and 4 triticale) have so far been notified since 1965 for cultivation in different agro-ecological regions of the country. These varieties are instrumental in strengthening the food security of the country. There are product specific varieties for bread, biscuits, pasta, etc or varieties tolerant to biotic stresses. Major wheat varieties (zone-wise, state-wise) developed during last twenty years are given in Tables 2.1 to 2.3. Recently, to encounter malnutrition among masses, efforts have been made to develop bio-fortified varieties as a solution to fight against malnutrition. WB 02 (high zinc, 22 ppm, & iron, 40.0 pm), HPBW 01 Iron (40.0 ppm and zinc 40.6 ppm) are some of the latest bio-fortified varieties of wheat. The detail of biofortified varieties of wheat is mentioned in Table 2.4.

Varieties released for major zones of India

The wheat cultivated area in India occupies around 30 million hectare. The major wheat cultivated areas fall in the plain areas of Gangetic Plains, central and peninsular parts of the country which are divided into four major agro-ecologic mega-zones. Each zone has its unique features and agro-ecological parameters are described below:

North Western Plain Zone (NWPZ): This zone comprises Punjab, Haryana, Delhi, Rajasthan (except Kota and Udaipur Divisions), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua districts of Jammu and Kashmir, Una district and Paonta valley of Himachal Pradesh and Terai region of Uttarakhand. This zone has the largest (~12 million ha) area and contributes about 55% of the total wheat production in the country.

With assured irrigation facility available in almost 95% area, wheat is mainly cultivated under high fertiliser dose in this zone. Major part of this zone caters to irrigated, timely sown conditions (mainly rice-wheat rotation) followed by the irrigated, late sown (cotton-wheat in Punjab and Haryana or sugarcane-wheat in western UP). The intensive tillage and excessive use of fertiliser and water resources are increasing the cost of cultivation on one hand and causing air pollution due to residue burning on the other hand. Further, continuous and injudicious use of weedcides has resulted into resistance of most dominant

Table 2.4: Biofortified varieties of wheat

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
WB 02	Rich in iron (40.0 ppm) and zinc (40.0 ppm) in comparison to 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for irrigated timely sown conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhand	51.6	142	ICAR–Indian Institute of Wheat and Barley Research, Karnal
HPBW 01	Rich in iron (40.0 ppm) and zinc (40.6 ppm) in comparison to 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for irrigated timely sown conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhand	51.7	141	Punjab Agricultural University, Ludhiana
Pusa Tejas (HI 8759) durum	Rich in protein (12.0%), iron (41.1 ppm) and zinc (42.8 ppm) in comparison to 8–10% protein, 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for irrigated timely sown conditions in <i>rabi</i> . Madhya Pradesh, Chhattisgarh, Gujarat, Rajasthan (Kota and Udaipur Division) and Uttar Pradesh (Jhansi Division)	57.0	117	ICAR–Indian Agricultural Research Institute, Regional Station, Indore

(Contd.)

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
Pusa Ujala (HI 1605)	Rich in protein (13.0%), iron (43.0 ppm) in comparison to 8–10% protein and 28.0–32.0 ppm iron in popular varieties	Suitable for timely sown restricted irrigated conditions in <i>rabi</i> . Maharashtra and Karnataka	30.0	105	ICAR–Indian Agricultural Research Institute, Regional Station, Indore
HD 3171	Rich in zinc (47.1 ppm) in comparison to 30.0–32.0 ppm iron in popular varieties	Suitable for timely sown rainfed conditions in <i>rabi</i> . Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal, Asom and plains of North Eastern States	28.0	122	ICAR–Indian Agricultural Research Institute, New Delhi
HI 8777 (durum)	Rich in iron (48.7 ppm) and zinc (43.6 ppm) in comparison to 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for timely sown rainfed conditions in <i>rabi</i> . Maharashtra, Karnataka and plains of Tamil Nadu	18.5	108	ICAR–Indian Agricultural Research Institute, Regional Station, Indore
MACS 4028 (durum)	Rich in protein (14.7%), iron (46.1 ppm) and zinc (40.3 ppm) in comparison to 8–10% protein 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for rainfed, low fertility, timely sown conditions in <i>rabi</i> . Maharashtra and Karnataka	19.3	102	Agharkar Research Institute, Pune
PBW 752	Rich in protein (12.4%) in comparison to 8–10% in popular varieties	Suitable for late sown irrigated conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhand	49.7	120	Punjab Agricultural University, Ludhiana

(Contd.)

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
PBW 757	Contains high zinc (42.3 ppm) in comparison to 30.0–32.0 ppm zinc in popular varieties	Suitable for very late sown irrigated conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhnad	36.7	104	Punjab Agricultural University, Ludhiana
Karan Vandana (DBW 187)	Rich in iron (43.1 ppm) in comparison to 28.0–32.0 ppm in popular varieties	Suitable for timely sown irrigated and fertility conditions in <i>rabi</i> . Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhnad	48.8	120 days (NEPZ), 146 days (NWPZ) and 158 days (high fertility)	ICAR-Indian Institute of Wheat and Barley Research, Karnal
DBW 173	Rich in protein (12.5%) and iron (40.7 ppm) in comparison to 8–10% protein and 28.0–32.0 ppm iron in popular varieties	Suitable for late sown irrigated conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh	47.2	122	ICAR-Indian Institute of Wheat and Barley Research, Karnal

(Contd.)

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
UAS 375	Rich in protein (13.8%) in comparison to 8–10% in popular varieties	(except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhand Suitable for timely sown rainfed conditions in <i>rabi</i> . Maharashtra and Karnataka	21.4	103	University of Agricultural Sciences, Dharwad
DDW 47	Rich in protein (12.7%) and iron (40.1 ppm) in comparison to 8–10% protein and 28.0–32.0 ppm iron in popular varieties	Suitable for timely sown restricted irrigated conditions in <i>rabi</i> . Madhya Pradesh, Gujarat, Rajasthan and Chhattisgarh	37.3	121	ICAR–Indian Institute of Wheat and Barley Research, Karnal
PBW 771	Rich in zinc (41.4 ppm) in comparison to 30.0–32.0 ppm in popular varieties	Suitable for late sown irrigated conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhand	50.3	120	Punjab Agricultural University, Ludhiana
HI 8802 (durum)	Rich in protein (13.0%) in comparison to 8–10% in popular varieties	Suitable for timely sown rainfed conditions in <i>rabi</i> . Maharashtra, Karnataka and plains of Tamil Nadu	29.1	109	ICAR–Indian Agricultural Research Institute, Regional Station, Indore
HI 8805 (durum)	Rich in protein (12.8%) and iron (40.4 ppm) in comparison to 8–10% protein and 28.0–32.0 ppm iron in popular varieties	Suitable for timely sown rainfed conditions in <i>rabi</i> . Maharashtra, Karnataka and plains of Tamil Nadu	30.4	105	ICAR–Indian Agricultural Research Institute, Regional Station, Indore

(Contd.)

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
HD 3249	Rich in iron (42.5 ppm) in comparison to 28.0–32.0 ppm in popular varieties	Suitable for timely sown rainfed conditions in <i>rabi</i> . Eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal (excluding hills), Odisha, Asom and plains of North Eastern States	48.8	122	ICAR–Indian Agricultural Research Institute, New Delhi
MACS 4058 (durum)	Rich in protein (14.7%), iron (39.5 ppm) and zinc (37.8 ppm) in comparison to 8–10% protein, 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for timely sown restricted irrigated conditions in <i>rabi</i> . Maharashtra and Karnataka	29.6	102	Agharkar Research Institute, Pune
HD 3298	Rich in protein (12.1%) and iron (43.1 ppm) in comparison to 8–10% protein and 28.0–32.0 ppm iron in popular varieties	Suitable for very late sown irrigated conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Uttarakhand (Tarai region)	43.7	103	ICAR–Indian Agricultural Research Institute, New Delhi
HI 1633	Rich in protein (12.4%), iron (41.6 ppm) and zinc (41.1 ppm) in comparison to 8–10% protein, 28.0–32.0 ppm iron and 30.0–32.0 ppm zinc in popular varieties	Suitable for late sown irrigated conditions in <i>rabi</i> . Maharashtra, Karnataka and plains of Tamil Nadu	41.7	100	ICAR–Indian Agricultural Research Institute, Regional Station, Indore

(Contd.)

Name	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
DBW 303	Rich in protein (12.1%) in comparison to 8–10% protein in popular varieties	Suitable for irrigated timely sown and high fertility conditions in <i>rabi</i> . Punjab, Haryana, Delhi, Rajasthan (excluding Kota and Udaipur Division), Western Uttar Pradesh (except Jhansi Division), Jammu and Kathua District of Jammu & Kashmir, Paonta Valley and Una District of Himachal Pradesh and Tarai region of Uttarakhand	81.2	156	ICAR–Indian Institute of Wheat and Barley Research, Karnal
DDW 48 (durum)	Rich in protein (12.1%) in comparison to 8–10% protein in popular varieties	Suitable for timely sown irrigated conditions in <i>rabi</i> . Maharashtra, Karnataka and plains of Tamil Nadu	47.4	111	ICAR–Indian Institute of Wheat and Barley Research, Karnal

Source: Yadava et al, 2020

weed *Phalaris minor* which is threatening the wheat cultivation in many parts of this zone. Thus, resource conservation technologies are becoming the need of the hour. Reduced or zero tillage are becoming popular in North Western Plains of India.

Yellow rust, terminal heat stress during grain filling stage, decline of water table and environmental pollution are the major constraints in wheat production. Development of high yield potential, disease resistant and climate resilient varieties are the major objectives of the wheat improvement programmes in NWPZ. Various varieties such as HD 2009, HD 2285, HD 2329, PBW 343, HD 2967 and HD 3086 occupied large areas and had farmers' preference as landmark varieties of this zone. To boost the area under zero-till wheat, efforts have been made to bred varieties suitable to such production system (component of conservation agriculture). Recently, wheat varieties HD CSW 18 is the first variety specifically bred for conservation agriculture which will reduce water requirement, less inputs and will help in residue management. Another such variety HD 3117 has also been released for late sown situation under conservation agriculture. However, zone-wise wheat varieties released/notified during last 20 years are mentioned in Table 2.1.

North Eastern Plains Zone (NEPZ): This zone comprises eastern Uttar Pradesh, Bihar, Jharkhand, Assam, West Bengal plains. This zone occupies 27% of area (around 8 million ha) and contributes 22% of wheat production in the country. The wheat productivity of this zone hovers around 2.0–2.1 t/ha which is far lower than the national productivity of 3.0 t/ha. Rice-wheat system is the most common cropping pattern followed in this zone. In Bihar, the rice-wheat, maize-wheat and pulse-wheat cropping patterns are followed, whereas rice-wheat and potato-wheat cropping patterns occupy most of the wheat growing areas in Bengal. The major factors of low productivity of this zone are harsh environment like high temperature at the time of crop growth and grain filling, moisture stress due to lack of proper irrigation facilities, micro-nutrient deficiencies and toxicities in soil, water-logged situation due to excess rains in some parts. Wheat varieties such as UP 262 and HUW 234 were quite popular among the farmers of this zone due to their wider adaptability and input responsiveness. Recently released varieties such as HD 2967, DBW 14, DBW 39, CBW 38, K 0307, K 1006, HD 2733, NW 5054 occupy sizeable area in the zone.

Central Zone (CZ): The Central Zone comprises Madhya Pradesh, Chhattisgarh, Gujarat, Rajasthan (Kota and Udaipur divisions) and Jhansi division of Uttar Pradesh. This zone is known for premium quality bread wheat having typically hard lustrous grains with high gluten strength. This zone is also having sizeable area under durum wheat. The zone is characterized by black cotton soil classified as vertisols. The vertisols have high water retention capacity producing high yield under limited water availability also. Soybean-wheat has emerged as most prevalent cropping system after 1980. Constraints of irrigation water availability and high temperature all through the crop cycle limit the exploitation of yield potential. Lok 1 wheat variety, developed by Lokbharti Gramvidyapith, Sanosara, Gujarat was the most preferred wheat

variety by the farmers of this zone till 2005. Varieties such as Jairaj, Sujata (HI 617), Swati (HI 787), HI 8498, MP4010, GW 273, GW 322, GW 366 and HI 1544 have made impact in increasing the production and productivity of this zone. Detail of zone-wise durum and dicoccum wheat varieties released/notified during last 20 years are available in Table 2.2.

Peninsular Zone (PZ): This zone comprises Maharashtra and Karnataka. All the three species of wheat, viz. aestivum, durum, and dicoccum are cultivated in this zone. Bread wheat cultivation is concentrated under irrigated environments, whereas the cultivation of durum and dicoccum wheat is generally confined to rainfed/restricted irrigation situation. In this zone, optimum ambient cool temperature for cultivation exists for a very short period causing the wheat to mature in around 90–100 days as compared to 140–150 days in the NWPZ. Sorghum-wheat is one of the most prevalent cropping systems in western Marathwada and Vidarbha regions of Maharashtra and northern parts of Karnataka. Maize-wheat and sunflower-wheat cropping sequence are being practised in some parts of Karnataka. High temperature throughout the crop cycle, light soils, imbalanced use of organic and inorganic fertilizers, lack of sufficient irrigation are the major reasons for low productivity (1.5–1.6 t/ha). Bread wheat cultivation in peninsular zone was revolutionized with the release of variety DWR-162 developed at Dharwad centre in 1993. Varieties HD 2189, NI 5439, NIAW 917 and MACS 6222 are some of popular varieties of this zone.

Earlier, Southern Hills Zone (SHZ) comprises hilly areas of Tamil Nadu and Kerala falling in the Nilgiri and Palni hills of southern plateau was considered as a separate zone. Since the area under wheat cultivation in this zone has significantly reduced over the years due to preference for tea and vegetable cultivation, hence this zone is merged with PZ from 2015–16 onwards. Since the present area under wheat cultivation in SHZ is too less to qualify for delineation as a separate zone, this zone has ceased to be classified as a separate zone. Moisture stress and acidic soils are the major constraints in wheat production.

Northern Hill Zone (NHZ): This region comprises hilly terrains of Northern region extending from Jammu & Kashmir to North Eastern States. The NHZ comprises J&K (except Jammu and Kathua districts); Himachal Pradesh (except Una and Paonta Valley); Uttarakhand (except Tarai area); Sikkim, hills of West Bengal and North Eastern states. In this zone, the area under wheat is around 1.0 million ha, whereas the productivity of wheat is poor and ranges from 1.5–1.6 t/ha. Moisture stress is the most important factor responsible for low productivity besides small and fragmented holdings, poor soil fertility, shallow soil depth, frost damage, poor use of fertilizers. High incidence of weeds and diseases, particularly yellow rust, brown rust and loose smut are the other factors that limit the productivity. Wheat is cultivated in the hills at different altitudes under different crop rotations adapted at different elevations. In NHZ, sowing is generally done under rainfed conditions in

October/November with residual moisture and harvesting takes place in May/June. In higher hills of Leh (J&K) and Lahaul and Spiti (H.P.), the winter is severe, causing the crop is to be raised between May to September. Research institutes and state agricultural universities in this zone have evolved a good number of high yielding rust resistant varieties; among which VL 616, HS 240, HPW 251 and recently released varieties, HS 507, VL 907, VL 892, HPW 349 are quite popular among the farmers of this region.

CROPPING SYSTEMS

In India many rotations of crops involving wheat are feasible. In the irrigated areas a variety of crops like rice, jowar, pearl millet (bajra), maize, cotton, toria, pigeon pea, moong, urad bean, etc. are grown in rotation with wheat. Some of the most common cropping systems are as follows.

<i>Rotation</i>	<i>Duration</i>
1. Rice—wheat	1 year
2. Maize—wheat	1 year
3. Pigeon pea—wheat	1 year
4. Pearl millet—wheat	1 year
5. Maize—wheat—cotton—berseem (Egyptian clover)	2 years
6. Rice—wheat—sorghum—chickpea	2 years
7. Maize—wheat—sugarcane—ratoon	3 years
8. Maize—wheat—green manuring—potato—sugarcane	3 years

With the development of short duration and photo-insensitive varieties of various crops in areas with assured irrigation, a series of cropping sequences with wheat as one of the main crops have been developed. These cropping sequences have been designated as 'Crop Cafeteria' which denotes that farmers can choose any cropping sequence best suited to their area depending on agronomic considerations, marketing facilities for the produce, profitability of the cropping sequence, etc. The flexibility in sowing time of high-yielding dwarf varieties of wheat and the possibility of growing a successful crop of late sown wheat make possible the adoption of multiple cropping with wheat as one of the main crops of assured irrigated areas. A number of cropping sequences have been tried successfully at various places. Some of them are as follows.

1. Maize—toria—wheat	1 year
2. Maize—potato—wheat	1 year
3. Pigeon pea—wheat—moong (green gram)	1 year
4. Soybean—wheat—moong (green gram)	1 year
5. Rice—wheat—lobia (cowpea)	1 year
6. Rice—potato—moong (green gram)	1 year
7. Maize—toria—wheat—moong (green gram)	1 year
8. Maize—wheat—cheena (proso millet)	1 year

Mixed cropping of wheat with mustard, chickpea, linseed is common in most of the areas of wheat growing belt. Nowadays intercropping with autumn sugarcane and potato is also becoming popular in some of the parts of northern India.

FIELD PREPARATION

As a general rule wheat crop requires a well-pulverised but compact seedbed for good and uniform germination. In irrigated areas wheat is usually sown after *Kharif* crops like maize, paddy, jowar, Pearl millet, black gram, moong, etc. After the harvest of previous crop, the field should be ploughed with disc or mouldboard plough. Where tractor is available one deep ploughing followed by two to three harrowings with disc or tines and 2–3 planking should be given to prepare a well-pulverised seedbed. Where bullocks are the source of power, deep ploughing followed by two to three harrowings or four to five intercross ploughing with local plough should be done. Planking should be done after each ploughing. Avoid powdery seedbed. One pre-sowing irrigation 7–10 days before seeding is necessary to ensure good germination. In case where previous crop was sugarcane, toria, arhar, etc. the pre-sowing irrigation for wheat may be given in the previous standing crop so that field may become available for its preparation and sowing, soon after the harvest of the previous crop. One light cultivation and levelling is required before sowing. Delay in sowing causes drastic reduction in yield in late sown wheat. In certain areas crops are attacked by white ants and gujhia weevil. To protect young seedlings from white ants and gujhia weevil mix chlorpyrifos 1.5% dust in soil @ 25 kg/ha at the time of last ploughing.

In rainfed areas field preparation should be done with great care as conservation of moisture is dependent on it. Fields are usually prepared by giving one deep ploughing with iron plough followed by two to three times with local plough and planking. In these areas ploughings should be done in the evening time and furrows should be kept open whole night to absorb some moisture from dew. Planking should be done after each ploughing early in the morning. All the possible efforts should be made to conserve moisture for the sowing of wheat crop.

SEED AND SOWING

Selection of Seed

Only healthy seeds of right variety suitable for a particular locality should be selected for sowing. There should not be any mixture of seeds of other varieties or weeds. The seed should be purchased from a reliable source. Always use certified seed. If seed is not treated, treat it with Vitavax or Thiram @ 2.5 g/kg seed.

Time of Sowing

It is one of the important aspects in obtaining good yields of wheat. It has a marked influence on the yield of wheat. The optimum time of sowing varies

widely over the wheat growing areas. In fact, the optimum time of wheat sowing depends upon the following factors.

1. Type of variety (duration)
2. Weather conditions
3. Soil temperature
4. Irrigation facilities
5. Land preparation
6. Availability of inputs

In general, the maximum productivity potential of promising wheat varieties under irrigated conditions is attained by sowing them between the 10th and 25th November in all the zones other than the peninsular zone. However, the sowing dates should be adjusted in such a manner that the mean daily temperature drops down to 20 to 22°C. Rainfed wheat is generally sown during the period from the second fortnight of October to early November.

The recommended optimum sowing dates for various zones have been given in Table 2.5.

Table 2.5: Sowing of wheat in different zones under various ecosystems		
Ecosystem	Zone	Optimum sowing time
Rainfed	All zones	End of October to first week of November
Irrigated timely sown	A. North-western plains zone, North-eastern plains zone, Central zone	First week of November to third week of November
	B. Northern hills zone	Second fortnight of October to first fortnight of November
	(a) Mild hills (up to 1700 m)	First fortnight of October
	(b) High hills (above 1700 m above sea level)	
Irrigated late sown	C. Southern hills zone (two crops in a year)	(i) October for cool season crop (ii) May/June for the summer season crop
	A. North-western plains zone	Before 25th December
	B. North-eastern plains zone	Before 15th December
	C. Central zone	Before 15th December
	D. Peninsular zone	Before 10th December

Under specific circumstances wheat is sown in the month of December too. In late sown wheat, only short duration varieties should be sown because there is comparatively less reduction in their yields compared to long duration varieties. When wheat is sown in the month of December, there is a drastic reduction in yield (Table 2.6). November onwards delay in sowing by each day causes reduction of 41.6 kg in north western plains and 56 kg/day/ha in north-eastern plains of the country. In spite of the development of the best production technology, late sowing usually results in a poor stand as well as the inadequate vegetative growth of the crop. The reproductive development in late sown wheat is also poor on account of the quick rise of ambient temperature towards the maturity stage.

Table 2.6: Effect of time of sowing on grain yield of wheat

Area/Zone	No. of experiments	Date of sowing				Rate of reduction in yield/day/ha (kg)*
		1 Nov.	16 Nov.	1 Dec.	16 Dec.	
North-western plains	11	3650	3780	3000	2551	41.6
North-eastern plains	4	4750	3670	3110	2230	56.0
Central parts	6	4100	4300	3750	3050	41.6
Hilly areas	2	2520	1800	1750	1700	18.2
Coastal areas	2	2620	2790	2340	2050	24.6

Source: Annual Reports of All India Coordinated Wheat Improvement Project 1972–73, 1973–74.

* Based on difference in yield of normal sowing and last date of sowing.

Seed Rate and Spacing

Seed rate varies with variety used depending upon its seed size and germination percentage, tillering ability, time of sowing, moisture content in the soil at the time of sowing and method of sowing. Usually, a seed rate of 100 kg/ha is sufficient under favourable conditions of normal sowing. For varieties with bold grains and under late sown conditions, seed rate should be increased to 125 kg/ha. In case where wheat is to be sown by dibbler, a seed rate of 25–30 kg/ha is sufficient.

For normal sown crop a spacing of 20 to 22.5 cm between rows is recommended. When sowing is delayed a closer spacing of 15 to 18 cm should be adopted.

Depth of Sowing

Depth of sowing is a very important aspect in successful cultivation of high yielding dwarf varieties of wheat. The coleoptile length is shorter in case of Mexican wheat as compared to tall varieties. The coleoptile length of high yielding Mexican dwarf varieties is about 5 cm. Therefore, seeds of these varieties should be covered not by more than 5 cm soil to ensure uniform and good germination. Seeds of semi-dwarf (one gene dwarf) varieties could be sown at the depth of 5–6 cm but seeds of three dwarf gene varieties should not be sown deeper than 5 cm. Similarly, in late sown crop, seeds should be sown shallow (about 4 cm deep) as deep sowing delays the emergence of seedlings by 2–3 days and heading by 5–6 days.

Methods of Sowing

Wheat is sown by four methods:

Broadcasting: In this method the seeds are broadcast and then worked in by harrowing in order to cover them. However, the seeds are not uniformly distributed in the field. This method of sowing is very insufficient and should not be encouraged. Germination of broadcast seed is relatively poor and the

plant stand is often irregular. Wastage of seed also results because most of the seed is left on the surface where they cannot germinate and may, therefore, be picked up and eaten by birds.

Behind local plough: A majority of farmers use this method. This method consists of dropping the seeds by hand into the furrows that have been opened with local plough. When seed is dropped in furrows by hand, it is called 'Kera' method and when it is dropped through a *Pora* or *Nai* or *Hazara* a special attachment with local plough, it is called 'Pora' method. In this method seeds are dropped at a depth of 5–6 cm and germination is satisfactory.

Drilling: In this method seed is sown by seed drill or ferti-seed drill. With the help of this implement seeds drop at uniform depth and results in uniform germination and regular stand. Seedbed should be fine and well-levelled free from clods and weeds for the use of seed drill or ferti-seed drill. Seed drills are easily available in the market. They may be either bullock driven or tractor driven. Ferti-seed drill should be used wherever possible to ensure uniform depth of sowing, proper placement of fertilisers and good germination.

Dibbling: This method is used in case where supply of seed is limited. Sowing is done with the help of a small implement known as 'Dibbler'. It is a wooden or iron frame with pegs. The frame is pressed in the field and lifted and then one or two seeds are dropped by hand in each of the hole. It is not a common method because it is a very time consuming process.

Zero tillage technique: This new method is used in rice-wheat cropping system where sowing of wheat is delayed beyond 25 November. Sowing is delayed due to multiple reasons, *viz.* preparation of field, uncertain rainfall and rice harvesting with traditional method. Out of these, the field preparation is one of the most important reasons, which causes delay in wheat sowing. Puddling in transplanted rice creates a hard pan in the field. After harvesting of rice crop, field requires at least 6–8 tillage operations in ploughing and harrowing for sowing of wheat, in which generally 10–15 days are required for proper field preparation. Yield of wheat decreases @ 30 kg/ha/day after 25 November sowing.

A zero-till-ferti-seed-drill machine has been developed at GB Pant University of Agriculture & Technology, Pantnager, by which direct sowing of wheat is done in rice field without ploughing. Use of Happy seeder developed in Punjab state is very good. Harvesting of paddy and sowing of wheat is done in time. This helps advancing the sowing of wheat as the time required for field preparation is saved. Zero tillage can be adopted with following precautions.

1. At the time of sowing there should be proper moisture in the field.
2. Rice should be harvested near the ground and the leftover stubble should not be more than 15 cm in height and field should be free from weeds.
3. At the time of sowing the seed-drill should be lifted up or lower down very slowly to avoid chocking of furrow opener by soil, otherwise seeds and fertiliser will not drill in the furrow.
4. Seed should be treated with vitavax or Bavistin @ 2.5 g/kg of wheat seed. Seed rate should be 140–150 kg/ha (20–25% higher).

5. Sowing depth should be maintained about 5–6 cm.
6. Light planker may be used behind the zero-tillage machine.
7. After sowing by zero-till-drill, other package of practices remain the same as in other methods.

The zero-till-ferti-seed-drill has knife type tines in place of shovel type and is suitable for sowing under zero-tillage conditions as well as conventional field preparation. The tines are fitted at a distance of 20 cm and have a provision to shift by 2.5 cm on either side. The machine is fitted with 2 boxes, one for seed and the other one for the fertiliser. On each box lever is provided along with locking bolts and marking to get known quantity/ha. Seedling depth can be manipulated by adjusting 2 side depth wheels with the help of screw bolts. Front driving wheel is provided with a groove to adjust as per requirement. A wooden platform is provided to keep a man to monitor the chocking of seed and fertiliser tube. Zero-tillage machines are provided with two lower link pins and a lift Patti to attach the machine with tractor.

Sowing of Wheat in Standing Stubbles of Rice with Happy Seeder

Rice-wheat system (RWS) is a major cropping system in the Indo-Gangetic Plains (IGP) of India covering nearly 10.5 million hectares including 4.1 million hectares of the north western states comprising of Punjab, Haryana and western Uttar Pradesh (NAAS, 2017). The cultivation of high yielding varieties in RWS has helped in ensuring food security of the country but at the same time has resulted in production of huge quantities of crop residues. Wheat straw is usually used as animal feed but paddy straw is not preferred as animal feed due to high silica content.

Paddy straw burning scenario: Paddy is largely harvested using combine harvesters and about 34 million tonne straw is produced in RWS. With the machine harvesting, the remaining straw is left in a windrow which is vulnerable for open field burning. Disposal or utilization of leftover residue is daunting task because the period between harvesting of paddy and clearing of fields/managing paddy straw is very narrow (2–3 weeks) before sowing of wheat. In paucity of time, farmers burn the residue and clear the field for sowing of wheat. It is estimated that in NW states of India about 23 million tons of rice residues are burnt annually contributing poor air quality and human respiratory ailments in intensive production system.

It is estimated that 25% nitrogen and phosphorus, 75% potash and 50% of the sulphur taken up by rice plants remains in the vegetative parts at maturity. One ton of paddy straw contains approximately 5.5 kg N, 2.3 kg P_2O_5 , 25 kg K_2O , 1.2 kg S, 50-70% of micro-nutrients absorbed by rice and 400 kg of carbon which are lost due to burning of paddy straw. The burning of paddy straw disturbs soil's natural environment and also have an adverse effect on microbial population of soil. Burning of paddy residue emits harmful gases like CO_2 , CO, NO_x , CH_4 and N_2O which contribute to air pollution and global warming. The burning of one ton of straw releases 3 kg particulate matter (PM), 60 kg

CO, 1460 kg CO₂, 199 kg ash and 2 kg SO₂. These gases affect human health due to general degradation in air quality resulting in aggravation of respiratory (like cough, asthma, bronchitis), eye and skin diseases. Fine particles can also aggravate chronic heart and lung diseases.

***In situ* residue management:** This method is a sustainable way of residue management for restoring soil fertility. Mulching and incorporation of straw in the soil are the two suggested methods of *in situ* straw management. Mulching can be practiced where rice is followed by wheat and incorporation can be adopted when rice is followed by vegetables. Continuously adopting *in situ* method of straw management will result in saving of 30 to 35% nitrogen; 20 to 25% potassium and substantial amount of organic carbon. Besides, *in situ* residue management helps in restoring microbial activities in the soil. The *in situ* crop residue management can be broadly classified into following groups: (i) incorporation of paddy residue into the soil using conventional tillage methods, straw chopping and mixing in the soil using tillage tools; (ii) retention of paddy straw as mulch on soil and sowing of wheat using Happy seeder.

Wheat sowing with Happy seeder in standing stubbles: Until recently, non-availability of suitable machinery was a major constraint to direct sowing of wheat in standing stubbles of combine harvested fields. This constraint has been resolved by development of Happy Seeder (HS) machine, which is recognized as a significant technological innovation for *in situ* residue management. Happy Seeder is a tractor-mounted machine that cuts and lifts rice straw, sows wheat, and deposits the straw as mulch. Therefore, happy seeder allows farmers to sow wheat immediately after their paddy harvest without burning residue for land preparation.

Super SMS for uniform distribution of straw: For efficient sowing of wheat using Happy seeder, the loose rice residue need to be uniformly spread across the field, but the traditional combine harvesters put the loose residues in narrow swath. Therefore, a straw management system (SMS) named as Super-SMS has been developed to equip the combine harvesters with mechanized straw spreaders, which help in uniformly spreading the rice residue as a part of the process of harvesting rice. Harvesting of rice by super SMS fitted combine harvesters facilitate direct sowing of wheat with happy seeder.

Advantage of Happy Seeder: Several advantages in terms of production, economics and environmental benefits have been observed with the concurrent use of SMS-fitted combines and happy seeder. After harvesting of rice crop, field requires 6–8 tillage operation for sowing of wheat. With happy seeder, wheat is sown directly in standing stubbles under residual moisture thus saving in preparatory tillage. Large scale demonstrations on happy seeder sown wheat clearly indicated 2–5 % increase in grain yield. Economic cost of production through saving in the cost of labour, fuel, chemicals, etc. There is saving of one irrigation due to elimination of pre-sowing irrigation which account for 1.0 million litres of water per hectare. Moreover, residue mulch reduces evaporation loss equivalent to about 45 mm (0.45 million liter) during the wheat season. Happy seeder sown wheat has also reduced risk of biotic and abiotic stresses by reducing weed growth, crop lodging and diseases infestation.



Fig. 2.5: Combine Harvester fitted with Super SMS in operation (see Colour Plate 2)



Fig. 2.6: Sowing of wheat with Happy Seeder in standing stubbles of paddy (see Colour Plate 2)

Mulching of straw improves soil health, by improving soil organic matter over time. Happy seeder sown wheat provides a viable alternative to residue burning, thus improves environment. Happy seeder (HS) sowing can be adopted with following precautions:

- The last irrigation to paddy crop should be planned in such a way that there is optimum soil moisture in the field at the time of sowing of wheat with HS.

- Depth of sowing should be properly (4–5 cm) maintained for proper germination. Higher seed rate (12–25%) than recommendation should be used when wheat is sown with HS
- Care should be taken that there is no clogging of seed and fertilizer tubes of HS.
- First irrigation should be light and applied at 25–30 days (in light textured soils) and 30–35 days after sowing (in medium to heavy textured soils). Apply irrigation after taking into account rainfall forecast.
- Regular monitoring of paddy crop in the months of September–October to check prevalence of stem borer. Grow recommended short to medium duration rice varieties to minimise pink stem borer infestation in succeeding wheat crop. Avoid early sowing of wheat.

MANURES AND FERTILISERS

Manures and fertilisers both play important roles in wheat cultivation. Use of manure improves the general physical condition and structure of the soil and its capacity to hold water. A liberal quantity of bulky manure should be applied in the field if available. About 10 to 15 tonnes of well rotted farm yard manure or compost should be applied four to six weeks before sowing and worked well into the soil. However, manures by themselves cannot meet, the high nutrient requirements of plants, which are also in short supply. It, therefore, becomes necessary to supplement manures with chemical fertilisers to get high yields. The high-yielding dwarf varieties of wheat fully exhibit their yield potential only when supplied with adequate quantities of nutrients at proper time. A crop of wheat yielding 50 quintals of grain/ha removes 100–150 kg nitrogen, 70–80 kg phosphorus and 125–150 kg potash from the soil. The response of a given variety of wheat to application of fertilisers, however, varies from field to field and from locality to locality.

Our soils are universally deficient in nitrogen but the status of phosphorus and potassium differs from place to place depending on native nutrient store and previous fertilisation history of the field. Fertiliser dose for wheat should, therefore, be related to the fertility status of the soil as indicated by soil tests. In case soil tests recommendations are not available the general guideline for fertilisation of high yielding dwarf varieties grown under different agroclimatic conditions laid down by the All India Co-ordinated Wheat Improvement Project should be followed. These are given in Table 2.7.

METHOD AND TIME OF APPLICATION

Three main factors have to be taken into account when applying fertilisers to wheat to get the best responses and profits. These are: (a) Application of correct doses of different nutrients after taking into account the requirements of the crop and soil's reserve supply, (b) application of these nutrients at the right time, and (c) in the correct way.

Table 2.7: Fertiliser recommendations for wheat in different agroclimatic regions

Condition	Zone	Recommended dose (kg/ha) of application			Time and method
Irrigated timely	All zones	120	60	40	Half of N and full quantity of P_2O_5 and K_2O should be drilled about 5 cm below the seed at the time of sowing. The remaining half N should be top dressed at first irrigation
Irrigated late sown crop	All zones	80	40	20	Same as above
Irrigated timely sown followed by a legume crop or fallow in <i>Kharif</i>	All zones	80	40	20	Same as above
Rainfed	Peninsular and central zones	80	40	20	Total quantity of N and P_2O_5 and K_2O should be applied 8–10 cm deep in soil at or before sowing
	Other zones	40	30	20	Same as above

Nitrogen

Split application of nitrogenous fertilisers is an established practice in wheat cultivation. Two-thirds or half of the dose should be applied at the time of sowing and remaining one-third or half quantity should be top dressed at first irrigation in medium and heavy soils. On sandy soils, top dressing should be made in two or three installments if heavy dose of nitrogen is to be applied. Under rainfed conditions full dose of nitrogen should be placed into the soil before sowing.

All nitrogenous fertilisers presently available in the market are equally effective for wheat under normal soil conditions. In calcareous soils (containing free lime) and in strongly alkaline soils, 10–30% of applied nitrogen may be lost through ammonia volatilisation, if urea or ammoniacal fertilisers are used for top dressing. In such cases calcium ammonium nitrate (CAN) should be preferred over urea.

Phosphorus and Potash

For phosphatic and potassic fertilisers, placement below the seed is the best method in most soils. Full dose of phosphorus and potash should be applied at the time of sowing. If possible place phosphorus and potash 3–5 cm to the side and 3–5 cm below the seed with the help of ferti-seed drill or by 'Pora' method. In case of phosphatic fertilisers, in general, one should not be concerned only with total phosphorus but also with water soluble phosphorus content. For wheat, phosphatic fertiliser must contain at least 50% of the total phosphorus in water soluble form and remaining portion in citrate soluble form. This is specially important for neutral and alkaline soils. For example, rock phosphate is relatively cheap but it will be of little use for the

crop if applied into a neutral or alkaline soil because of its exceedingly low solubility.

In acid soils (pH less than 6.0), use of basic slag or rock phosphate may be more profitable than superphosphate or diammonium phosphate because cost per unit phosphorus is much less in the former than in the latter.

Water soluble phosphatic fertilisers, such as diammonium phosphate and superphosphate are most effective when applied in granular form, whereas citrate soluble fertilisers—rock phosphate and basic slag are most effective in finely powdered form. Muriate of potash and potassium sulphate are the only potassic fertilisers presently available in the market. Both are equally good for wheat.

In addition to the major nutrients, N, P and K good responses to micronutrients, especially zinc, have been obtained in many areas. If zinc deficiency has been observed in the locality, it is advisable to apply 25–30 kg zinc sulphate/ha in the soil at the time of last ploughing. Acute zinc deficiency can be taken care of by soil application. If deficiency develops in the early stages of crop growth, spray a solution of 5 kg zinc sulphate and 2.5 kg lime in 1000 L of water/ha.

IRRIGATION

Adequate soil moisture is required for normal development of the wheat plant at all the stages of growth. The crown root initiation stage and heading stage are critical stages when plant suffers most due to moisture stress.

The following schedule of irrigation should be followed for dwarf varieties of wheat.

In case of dwarf high-yielding varieties, a pre-sowing irrigation should be given and crop sown when the field becomes fit for operation.

First Irrigation

The first irrigation to the standing crop could be given 20–25 days after sowing, i.e. at the crown root initiation stage. In cooler regions like hilly tracts and in late sown wheat, it is desirable to apply first irrigation approximately 25–30 days after sowing. Delay in giving this irrigation should be avoided as it would result in upsetting the synchronous tillering in these varieties, subnormal heads, poor root system and finally poor grain yield. It is the most critical stage for irrigation.

Second Irrigation

At tillering stage, within 40–45 days after sowing.

Third Irrigation

At late jointing stage, within 70–75 days after sowing.

Fourth Irrigation

At flowering stage, within 90–95 days after sowing. Irrigation at this stage is also important because during this period plants suffer most from soil moisture deficiency. The grain number and grain size are reduced considerably.

Fifth Irrigation

At dough stage, within 110–115 days after sowing.

The total number of irrigations required will vary depending upon soil type, winter rainfall, amount of water applied per irrigation.

Under limited supply of water the following schedule of irrigation should be adopted for best utilisation of available quantity of water.

1. Where only one irrigation is possible, give it at crown root initiation CRI stage, i.e. 20–25 days after sowing.
2. Where two irrigations are available, first irrigation should be given at CRI stage and second at flowering stage.
3. Where three irrigations are possible, first irrigation should be given at CRI stage, second at late jointing (boot) stage and third at milk stage. These recommendations strongly stress the importance of irrigation at CRI stage. It has been found that each week delay in first irrigation from CRI stage results in yield reduction of 2–3 quintals/ha.

WEED CONTROL

Weeds emerge with the emerging crop seedlings and if not controlled in the early stages of crop growth these may cause reduction in yield varying from 10 to 40% depending upon the intensity and kind of weeds present in an area.

Wheat field is generally infested from both dicot and monocot weeds. The major dicot weeds are: *Chenopodium album* (bathua), *Fumaria parviflora* (gajri), *Cirsium arvense* (kateli), *Anagallis arvensis* (krishna neel), *Melilotus alba* and *Melilotus indica* (senji), *Vicia saliva* (ankri), *Lathyrus* spp. (chatri matri), etc. Monocot weeds include: *Phalaris minor*, *Avena fatua* (wild oat), *Polypogon monspiliensis*, *Cyperus rotundus* (motha) and *Cynodon dactylon* (doob).

Generally, weeds are eradicated with the help of hoe, *khurpi*, etc. However, nowadays it has become difficult due to labour cost and unavailability of labour. Now a number of chemical weedicides are available that control the weeds in wheat rather effectively. Most common and effective herbicide to kill all the broad-leaved weeds in wheat field is 2,4-D. It is available in market under different trade names and each formulation has different amount of active ingredients as given in Table 2.8.

The above-mentioned quantity of 2,4-D should be mixed in about 400 to 600 L of water for spraying in an area of one hectare. The amount of water may, however, vary according to the type of sprayer in use. 2,4-D should be

Table 2.8: Different formulations of 2,4-D, amount of active ingredients in them and their quantity/ha for weed control

Herbicide	Trade name	Formulations	% active ingredient	Quantity per hectare
2,4-D*	Bladex G	Amine (liquid)	72	700 ml
	Weedar	Amine (liquid)	72	700 ml
	Bladex C	Easter (liquid)	36	1.4 L
	Weedone	Easter (liquid)	36	1.4 L
	Tafacide	Sodium salt (powder)	80	625 g
	Fernoxone	Sodium salt (powder)	80	625 g

Note: Information is illustrative and is not the recommendation of the product of a particular firm.

* 2,4-dichlorophenoxy acetic acid.

sprayed in wheat fields 32–35 days after sowing. This period may be extended to the maximum by 1 week. But after 40 days of sowing, spray of 2,4-D is not beneficial because by that time weeds have already done the damage to the crop, secondly, after 40 days weeds become woody in nature and are not likely to be killed easily with the recommended dose of 2,4-D. When 2,4-D is sprayed between 35 and 40 days, the ears of wheat have been found to suffer from malformation. Malformation adversely affects the uniformity of seed size and thereby reduces their value as grain and seed. Gappy spikelets result in reduction in total number of grains per head and finally lead to reduced grain yield. While spraying 2,4-D avoid drift of spray in the adjoining crop fields, because a slight drift of 2,4-D may spoil the pulse crop like pea, gram, lentil and mustard. It is desirable to spray 2,4-D when wind velocity is minimum.

Besides, 2,4-D, many new herbicides are also available in market which are very effective against broadleaf weeds.

Brands (herbicide)	Dose (g/ha)	Time of spray and amount of water
Algrip/Algrip Royal/Markgrip/Makoto 20 WP (metsulfuron)	25 g	30–35 days of sowing, using 350–400 litres of water
Aim/Affinity 40 DF (carfentrazone-ethyl)	50 g	25–30 days of sowing, using 500 litres of water
Lanfida 50 DF (metsulfuron + carfentrazone)	50 g	25–30 days of sowing, using 350–400 litres of water

Do not use any formulations of 2,4-D, metsulfuron, carfentrazone-ethyl and metsulfuron + carfentrazone if any broad leaf crop like raya, gobhi, sarson, gram is sown in wheat.

Among monocot weeds *Phalaris minor* is the major weed in most of the wheat fields. In certain localities the intensity of this weed is so high that it has become rather impossible to grow wheat crop. This weed belongs to family *Gramineae*, Genus *Phalaris*. On an average, each plant produces 10,000 to 30,000 seeds. It emerges with the germination of wheat and resembles wheat seedling, therefore, it is difficult to recognise it in the initial stage. There are few distinguishing features by which *Phalaris minor* can be differentiated wheat plants in the field (Table 2.9).

Table 2.9: Distinguish features of *Phalaris minor* and wheat

<i>Phalaris minor</i>	<i>Wheat</i>
1. Basal node remains pink in colour up to 50 days of plant growth.	1. Basal node is greenish yellow
2. Ligule is approximately three times large to that of wheat with no auricle	2. Ligule is very small and is formed with two leaf ears (auricles), which in most cases, are hairy.
3. Leaf colour is light green	3. Dark green leaf, depends upon the variety
4. Tillering is of rosette type	4. It grows erect
5. Tillers branch	5. Tillers do not branch
6. Produce 10,000 to 30,000 seeds per plants	6. Produces 60–70 seeds per plant
7. Test weight is 2 g	7. Test weight is about 40 g
8. Seeds are dark brown, oval in shape and much smaller than wheat	8. Seeds are amber in colour <i>hard</i> and of bigger size

Control of *Phalaris minor*

1. Cultural methods: Sow quick growing wheat varieties from last week of October to first week of November in narrow rows at 15 cm spacing. In fields having severe infestation of this weed, replace wheat with alternate crops like berseem, potato, raya, gobhi sarson and winter maize for 2 to 3 years. Preparation of soil mulch at sowing helps in eliminating the first flush of this weed.

2. Herbicides: *Phalaris minor* can be controlled with use of any of herbicides listed below. The herbicides can be applied within two days of sowing or before first irrigation or after first irrigation (Table 2.10).

3. Control of both grass and broadleaf weeds:

Grass and broadleaf weeds can simultaneously be controlled with use of any of below listed herbicides (Table 2.11):

4. Integrated weed management: Sowing wheat with happy seeder, in standing rice stubbles, significantly reduces weed pressure and soil weed seed bank, particularly of *gulli danda*. Integration of happy seeder with herbicides and hand pulling of escaped weed plants improves weed control and deplete soil seed bank further.

Weed control in durum wheat: All the above mentioned pre- and post-emergence herbicides at recommended dose and time can be used for weed control in durum wheat, except Total/Markpower/Atlantis/Accord Plus/Shagun 21-11/ACM-9. Apply 500 g of isoproturon group of herbicides at 40–45 days after sowing in medium to heavy textured soils and do not use isoproturon on light textured soils.

Useful hints for improving the efficiency of herbicides

- Spray of herbicides should be done on clear days and spray should be as uniform as possible for better results. After spray, flush the spray pump

Table 2.10

Table 2.10		
Brands (herbicide)	Dose per ha	Time of spray and amount of water
(a) Pre-emergence (good soil moisture is highly desirable)		
Stomp/Dost/Penda/Markpendi/Pendin/ Bunker/Zakiyama 30 EC (pendimethalin)	3.75 litres	Within two days of sowing, using 500 litres of water
Awkira 85 WG (pyroxasulfone)	150 g	
Platform 385 SE (pendimethalin + metribuzin)	2.5 litres	
(b) Post-emergence (before first irrigation)		
Arelon/Delron/Hilproturon/Ronak/ Nocilon/Wonder/Milron/Agrilon/Totalon/ Agrilon/Shivron/Carelon/Marklon/ water	300 g (in light-textured soil), 400 g (in medium-textured soil), 500 g (in heavy-textured soil)	Spray 2–3 days before first irrigation, using 350–400 litres of
Jai-roturon/Isoguard/Dhar/Rakshak/ Prowl/Kanak/Isotox/Isohit/Ciluron/ Isocin 75 WP (isoproturon)*		
Leader/SF-10/Safal/Marksulfo 75 WG (sulfosulfuron**)	32.5 g	
(c) Post-emergence (after first irrigation)		
Arelon/Delron/Hilproturon/Ronak/ Nocilon/Wonder/Milron/Agrilon/Totalon/ Agrilon/Shivron/Carelon/Marklon/ Jai-roturon/Isoguard/Dhar/Rakshak/ Prowl/Kanak/Isotox/Isohit/Ciluron/ Isocin 75 WP (isoproturon)	500 g for all types of soil	30–35 days of sowing using 350–400 litres of water
Topik/Point/Moolah/Topple/Columbus 15 WP (clodinafop 15 WP)	400 g	
Axial 5 EC (pinoxaden)	1000 ml	
Puma Power 10 EC (fenoxaprop-p-ethyl)	1000 ml	
Leader/SF-10/Safal/Marksulfo 75 WG (sulfosulfuron**)	32.5 g	

* Do not use isoproturon group of herbicides in areas where there is problem of resistance

** Do not use sulfosulfuron group of herbicides if any broadleaf crop is sown in wheat and where jowar/maize to be sown after wheat thoroughly with water and then with washing soda solution (0.5%) to remove traces of herbicides, as contaminated spray pump may be phytotoxic when used for spray on other crops.

- In areas where there is problem of resistance in *Phalaris minor*, do not use isoproturon group of herbicides.
- If raya, sarson or gobhi sarson is sown in wheat as intercrop, use isoproturon, clodinafop or fenoxaprop group of herbicides at recommended doses.
- Use flood jet nozzle for pre-emergence herbicides and flat fan nozzle for post-emergence herbicides.
- Change the herbicide group every year to prevent the development of resistance in weeds.

Table 2.11

Brands (herbicide)	Dose per ha	Time of spray and amount of water
Total/Markpower 75 WG (sulfosulfuron + metsulfuron)	40 g	30–35 days of sowing, using 150 litres of water
Atlantis 3.6 WDG (mesosulfuron + iodosulfuron)	400 g	
Accord Plus 22 EC (fenoxaprop + metribuzin)	1250 ml	
Shagun 21-11 (metribuzin + clodinafop*)	500 g	
ACM-9 (metribuzin + clodinafop*)	600 g	
Tank-mix of clodinafop 15 WP, fenoxaprop-p-ethyl 10 EC with 2,4-D/metsulfuron 20 WP	Recommended doses as per	35–45 days of sowing in 150 litres of water
Tank-mix of isoproturon formulations and 2,4-D sodium salt or ethyl ester**	<i>Phalaris minor</i> and broad leaf weeds alone	

* Preferably use where there is a problem of multiple herbicide resistance in *Phalaris minor*, do not use on light texture soil

** Only in areas where *Phalaris minor* has not evolved resistance to isoproturon

- Some weed plants may escape after the application of herbicides. These plants should be uprooted before they produce seeds. This practice will reduce the weed problem in next crop of wheat.

DISEASES

Wheat crop suffers from several diseases which reduce its yield and quality. The major diseases of wheat are rusts, alternaria leaf blight, loose smut, Karnal bunt, powdery mildew and yellowing in the seedling stage.

Yellowing in the Seedling Stage

Yellowing of wheat at seedling stage can be caused by nutrient deficiency, bad weather conditions, poor drainage, and attack of *Alternaria* and *Drechslera* sp. or soil infestation with cereal cyst nematode.

A general yellowing of the leaves and necrosis occurs especially starting from the tips and along the edges. Later on, necrotic area develops within the chlorotic tissue, there is stunting and general decline. In case of zinc deficiency, the plants remain stunted and bushy; leaves become chlorotic, stocky and break in the middle. Yellowing of young leaves may be due to sulphur deficiency, whereas yellowing of older leaves could be due to nitrogen deficiency.

Control Measures

- In light soil, add 62.5 kg zinc sulphate per hectare. One such application will be enough for 2–3 years.
- Spray 3% urea solution (3 kg in 100 litres of water). To cover the crop thoroughly, spraying may be done cross-wise and a total volume of 750 litres of water per hectares should be used.

- Give proper irrigation to counteract the effect of frost. Avoid excessive irrigation.
- If the cereal cyst nematode is present in the soil, apply furadan 3 G @ 32.5 kg per hectare at sowing time.
- Apply 250 kg gypsum per hectare for correcting sulphur deficiency.

Rusts

Rusts are caused by three different species of the fungus *Puccinia*. Brown and yellow rusts are particularly important in the major wheat growing areas of the north-western part of the country. Black rust appears quite late in these areas and normally cannot cause substantial damage except in wheat fields sown very late. However, black rust appears in severe forms in the southern, central and eastern India and causes significant damage.

Brown Rust

This rust is caused by a fungus known as *Puccinia recondita tritici*. The small, round-oval uredial pustules of brown rust develop mainly on the leaves but in severe attacks, these appear on sheath and stem as well. The uredial pustules are bright orange in colour. These are never in rows but are either in small clusters or irregularly scattered.

Brown rust spreads fast on susceptible wheat varieties during warm and humid environmental conditions. In case of severe attack of the disease, plants mature early, produce light and shrivelled grains and poor development of root system. This rust is most widespread in the country and generally the most damaging in several areas.

Yellow Rust

This rust is caused by the fungus, *Puccinia striiformis*. In the mild attack of this rust, uredia are formed chiefly on the leaves, but in case of severe attack, these appear on leaf sheaths, stalks and glumes as well. The uredial pustules are oval in shape and lemon-yellow in colour and are formed in long streaks or rows. The pustules of yellow rust are smaller than those of brown rust. Appearance of lemon-yellow pustules in rows is characteristic features of yellow rust. In severe attacks, however, these rows are not distinct, as large patches of the plant become covered with crowded pustules.

Unlike other rusts, yellow rust is restricted to those areas, where temperature is considerably low during the wheat growing season. Thus yellow rust is a problem of the hills, foot-hills and north-western part of the country. Since yellow rust develops early in the season, damage to young plants is severe.

Black Rust

This rust of wheat is caused by the fungus, *Puccinia graminis tritici*. The uredial pustules occur on stem, leaf sheath, leaves and earheads but the stem is often most severely affected. The pustules of black rust are reddish-brown in colour and elongated in shape. This rust spreads fast under relatively warmer and

humid environmental conditions. By the time the crop matures, dark, black, elongated tetial pustules are formed. The name black rust was given to this rust due to the prominence of its dark black telia.

Black rust, though prevalent all over the country, appears in epidemic forms in the southern, central and eastern India, which are characterised by high temperatures in the wheat growing season. Black rust is a killer of wheat plants and in severe infection there is heavy crop failure.

Integrated control management of rusts

- Grow brown rust resistant (PBW 725, PBW 677, Unnat PBW 343, Unnat PBW 550, PBW 1 Zn, WHD 943, PDW 291 and PBW 660) varieties as mentioned in varieties.
- For control of brown rust, spray the crop with 500 ml Tilt 25 EC/Shine 25 EC/Bumper 25 EC/Stilt 25 EC/Compass 25 EC/Markzole 25 EC (propiconazole) in 500 litres of water/hectare as soon as the disease is noticed.
- Grow yellow rust resistant (HD 3086, PBW 723, PBW 725, WH 1105, PBW 502, PBW 752, WHD 943, PDW 291, PBW 660, DBW 88) varieties.
- Don't grow unrecommended varieties. Apply balanced dose of fertilisers as per recommendation.
- Monitor the crop from 2nd week of December onward particularly after irrigation or rain to locate the initial foci of infection.
- For effective control of yellow rust, spray the crop with 500 g Caviet 25 WG (tebuconazole) or 300 g Nativo 75 WG (trifloxystrobin + tebuconazole) or 500 ml Opera 18.3 SE (pyraclostrobin + epoxiconazole) or 500 ml Tilt 25 EC/Shine 25EC/Bumper 25 EC/Stilt 25 EC/Compass 25 EC/Markzole 25 EC (propiconazole) in 500 litres of water per hectare as soon as the disease is noticed.
- Initially only spot application surrounding infected area should be done.
- Regularly monitor the crop and repeat the spray as per need.

Loose Smut

Loose smut has now become a major problem of wheat crop. This destructive disease of wheat is caused by a smut fungus, *Ustilago nuda tritici*. Generally, diseased plants are indistinguishable from the healthy plants before heading, but diseased plants produce heads earlier than healthy plants. Terminal symptom in all the varieties is the production of black powder in place of wheat grains in the ears. Almost every ear of the diseased plant is converted into black powder.

The black powder is a mass of olive-green microscopic spores of the smut fungus. When spores are blown to flowers of healthy plants, they germinate on the female organ, stigma and lead to infection of the developing seed. The smut fungus thus reaches in the mature grain and remains dormant there until germination of the grain. From superficial examination at harvest time, infected grains cannot be distinguished from the healthy ones. When these grains are sown in the following season, the fungus inside the seed becomes active as the germination starts. The fungus grows inside the plant first behind the growing

point, keeping pace with apex of the growing shoot. As the ear formation starts, there is an accumulation of the fungus in the floral parts, which are completely destroyed due to formation of the black powder.

Control Measures

- Grow resistant varieties such as Raj 2296, K 8027, WHD 943, PDW 291, VL 646, VL 719 etc is the best method of control.
- Soak the wheat seed in ordinary water from 8 a.m. to 12 noon on any calm and sunny day during May/June. After 4 hours soaking, spread out the moist seed in the sun in a thin layer on cemented floor (pucca), on tarpaulin or sheets of cloth. Dry the seed completely and store in a dry place till sowing.
- Seed treatment with 2 ml Neonix 20 FS (imidacloprid+hexaconazole) per kg seed also provide good control.
- Loose smut disease can also be controlled by treating 100 kg seed with 32.5 ml Raxil Easy/Orius 6 FS (tebuconazole) by dissolving in 1000 ml water or 300 g Vitavax Power 75 WS (carboxin +tetramethyl thiurum disulphide) or 200 g Vitavax 75 WP (carboxin) or 100 g Tebuseed/Seedex/Exzole 2 DS (tebuconazole) per 100 kg seed.

Karnal Bunt

Karnal bunt or partial bunt, first observed in experimental seed plots at Karnal (Haryana) in 1930, was regarded as a very minor disease of wheat till recently. But now this disease has become a problem in many places in northern India, mainly in the Himalayan foot-hills and *Tarai* regions. Practically all the commercial varieties of wheat grown at present are susceptible to it. The disease reduces both quantity and quality of wheat. Flour prepared from wheat with more than 3% infected grains smells fishy and is unfit for human consumption.

This disease is caused by the fungus called *Tilletia indica*. The disease can be recognised when the grains have developed. A portion of the grain along its groove is converted into a black powdery mass. The embryo tissue, except in very severe cases, is generally not destroyed. The black powder gives a foul smell due to presence of trimethylamine. In a plant hill, all the ears are not affected and in an ear only few grains are infected.

Control Measures

- Grow resistant varieties, namely PBW 502, WHD 943, PDW 291, HS 507, HI 8737, etc.
- A single spray of 500 ml Tilt 25 EC (propiconazole) using 500 litres of water at ear emergence stage for the control of Karnal bunt is recommended in wheat meant for seed production only.

Alternaria Leaf Blight

This disease is caused by the fungus, *Alternant triticina*. Lowermost leaves are always the first to show the sign of infection, which gradually spreads to the upper leaves. The disease first makes it appearance as small, oval, discoloured

lesions, irregularly scattered on the leaves. The spots became irregular in shape as these enlarge and take up dark brown to grey colour. A bright yellow marginal zone is sometimes seen around the spots. As the disease progresses, several spots come closer and cover large leaf areas, eventually resulting in death of the entire leaf. In case of severe attack, leaf sheaths, awns and glumes are also infected. Black powdery spores of the fungus cover the lesions at this stage under moist conditions. These spores are disseminated by wind and cause disease on healthy leaves and plants. The disease spreads very fast under warm and humid conditions. Heavily infected fields present a burnt appearance.

Control Measures

1. Seed-borne infection can be controlled by treating seed with vitavax + Thiram 3 g/kg seed.
2. Apply adequate fertilisers and irrigation.
3. Alternaria leaf blight can also be controlled by 0.2% Zineb or Mancozeb 75 WP sprays. The fungicide may be sprayed as described for rusts. It is beneficial to mix urea @ 2–3% with Zineb at first and second sprays.

Powdery Mildew

Powdery mildew disease of wheat is caused by a fungus, *Erysiphe graminis tritici*. This disease is characterised by formation of white, powdery growth of the fungus on the upper surface of leaves. The white growth contains mycelium and spores of the fungus. Later on, the colour of the powdery growth becomes grey or brown. Under severe disease conditions, leaf sheaths, stems and earheads may also be covered by the fungus. Infected plants become stunted due to reduction in size and number of leaves and produce poor yield. This disease is common in the sub-montaneous areas of northern India, certain parts of Rajasthan and the hills.

Control Measures

- Grow resistant varieties to the disease like WH 283, WH 542, HD 2329, etc.
- If losses are expected to be high, spray with 300 g Nativio 75 WG (trifloxystrobin + tebuconazole) in 500 litres of water.
- Spray of systemic fungicide Bayleton 28 WP @ 2 g/L water.

Flag Smut or Leaf-smut

This disease is caused by *Urocystis agropyri*. Long narrow lead grey or black streaks or stripes running parallel to veins are formed on the leaves. The stripes eventually rupture and expose black sooty mass of spores.

Control Measures

- Practice shallow sowing. Rogue out the affected stools and destroy them.
- Seed treatment (100 kg seed) with 32.5 ml Orius 6 FS (tebuconazole) by dissolving in 1000 ml water or 300 g Vitavax Power 75 WS (carboxin +

tetramethyl thiurum disulphide) or 200 g Vitavax 75 WP (carboxin) or 100 g Tebuseed/Seedex/Exzole 2 DS (tebuconazole). Treatment should not be done earlier than one month of sowing as it affects seed germination. Seed treatment can be done effectively with the seed treating drum.

- Grow resistant varieties like WHD 943 and PDW 291.

Head Blight or Scab

This disease is caused by *Fusarium* spp. Individual spikelets or portion of earheads show premature bleaching or brown discolouration. Characteristic pinkish mycelium of the fungus may be visible on infected spikelets during humid conditions. The grain formation is either completely inhibited or the infected spikelets produce shrivelled chalky grains showing pinkish discolouration.

Control Measures

- Seed lots affected by scab should be cleaned thoroughly to eliminate shrivelled seeds.
- The incidence of this disease is more on durum varieties, their cultivation in highly humid areas, particularly near rivers should be avoided.

Leaf blight, glume blight and black tip of grains

Elongated brown spots and blotches appear on leaves and glumes. Ears are poorly filled, grains shrivelled, discoloured and black tipped. Use disease free seed.

Ear Cockle (*Mamni*) and Yellow Ear Rot (*Tundu*)

Yellow ear rot or *Tundu* disease is caused by *Anguina tritici* and *Rathyi bacter*. Diseased plants have spreading tendency and swollen base, leaves become crinkled and twisted. Earheads contain dark-brown, hard and roundish galls (*Mamni*) instead of grains. Severely diseased plants are stunted and may die at seedling stage. Occurrence of yellow, slimy mass indicates ear rot phase which prevents grain and gall formation.

Control Measure

- Put wheat seed in ordinary water and agitate vigorously for few minutes. Ear-cockle galls will float to the surface. These may be skimmed off with an ordinary sieve and burnt.

Molya

Plants become stunted with yellowing of leaves, reduced tillering, and absence of ears on some tillers or small ears with poorly filled grains. The root system of infected plants gets reduced in size and becomes bunched with profuse development of thin rootlets. Cysts (shining white bodies of female nematode) are seen attached to the roots at the later stage of the crop.

Control Measures

- Expose the soil to the hot sun by cultivation during May and June.
- Practise rotation with non-cereals in badly infested soils. Apply 30 kg Furadan 3G (carbofuron) per hectare at sowing time.

INSECT PESTS

Wheat is attacked by a number of insect-pests and rodents both in the field and in storage. Some of the most important and common ones are given as follows.

Termites

Termites damage the crop soon after sowing and sometimes near maturity. The damaged plant dry up completely and are easily pulled out. The plants damaged at later stages give rise to white ears. Infestation is heavy under unirrigated conditions and in the field where undecomposed farm yard manure is applied before sowing. Treat the seed at the rate of 1 g Cruiser 70 WS (thiamethoxam) or 4 ml Dursban/Ruban/Durmet 20 EC (chlorpyrifos) or 2 ml Neonix 20 FS (imidacloprid + hexaconazole) per kg seed. Dilute 100 g of Cruiser or 400 ml of Dursban/Ruban/Durmet or 200 ml of Neonix in 2.5 liters of water and spray the same on 100 kg seed spread as a thin layer on the *pucca* ground or tarpaulin or polythene. Seed treated with Neonix also control smuts of wheat. Seed treated with insecticide is less attacked by birds.

Gujhia Weevil

It attacks germinating seedlings. As a result of heavy infestation plants die out. Control measures for this insect is same as for termites.

Army Worms

This insect attacks wheat usually during March-April, however it is also observed in the month of December in fields having large loads of paddy straw. Caterpillars of this insect feed on plants particularly tender parts during night and hide during daytime. They damage leaves and earheads. For effective control of this pest, spray one liter of Ekalux (quinalphos) in 500 liters of water per hectare with hand-operated knapsack sprayer. For better effectiveness of the insecticide, spraying should be done in the evening when armyworm larvae are more active. This insecticide will also control aphids. It can also be controlled effectively by using 15 kg Regent 0.3 G (Fipronil) by broadcasting or Coragen 18.5 SC (chlorantranilipore) 150 ml/ha.

Brown Wheat Mite, Aphids and Jassids

These are minor insects of wheat causing discolouration of leaves. It is of very small size and attack is more observed on rainfed wheat. However, to control these pests, spray quinalphos (Ekalux) 25 EC @ 2.0 L/ha in 1000 liters of water. Aphid alone can also be controlled by spraying 50 g of Actara/Taiyo 25 WG (thiamethoxam).

Aphid

Aphids damage the crop resulting in discoloration of leaves. Control aphids at ear head stage at economic threshold level of 5 aphids per ear heads recorded from 10 randomly taken ear heads in each of the 10 quarters of one hectare field. Since the aphids appear first on borders of the crop, spray only the infested strip to check their further spread. For control of aphids, spray 50 g of Actara/ Taiyo 25 WG (thiamethoxam) in 200–250 liters of water.

Gram pod borer

This insect attacks wheat at maturity. It feeds on the grains in the earheads. Damage is more where wheat follows cotton. Spray 2 liters Ekalux 25 EC (quinalphos) in 1000 litres of water per hectare with hand operated knapsack sprayer.

Pink stem borer

Pink stem borer (*Sesamia inferens*) generally attacks the wheat crop at seedling stage. The larva bore into the stem of young plant and kills the central shoot causing 'dead heart'. Spray 2 liters Ekalux 25 EC (quinalphos) in 1000 litres of water per hectare with hand operated knapsack sprayer.

RODENTS

Field Rats

They cause heavy loss to wheat crop and do considerable damage to the harvested crops lying in stacks in the field. For the control of field rats close all burrows in the evening and fumigate the reopened burrows of rats in the morning time with aluminium phosphide @ 1 tablet of 0.5 g/small burrow and 3.0 g/large burrow. In case of reappearance in the same field, bait with cumarin (ratafin) @ 1 kg of prepared bait (1 part cumarin: 19 part wheat or maize flour, 1 part molasses and 1 part mustard oil).

HARVESTING AND THRESHING

High-yielding dwarf varieties of wheat should be harvested when the leaves and stems turn yellow and become fairly dry. To avoid loss in yield crop should be harvested before it is dead ripe. When harvesting is not done in time, grain may be lost due to damage by rats, birds, insects, shattering and lodging. Timely harvesting ensures optimum grain quality and consumer acceptance. The right stage for harvesting is when there is about 25–30% moisture in grains. Harvesting is normally done with serrate edged sickles by hand. Bullock-driven reapers are also used occasionally. Combines are also available which can do harvesting, threshing and winnowing wheat crop in single operation. After harvesting the crop by hand, it is dried for three to four days on the threshing floor and then threshing is done by trampling bullocks or olpad thresher

attached to bullocks. Nowadays power driven stationary threshers are becoming more popular because these are easy in operation and hasten the process.

YIELD

When cultivation of high-yielding dwarf varieties of wheat is done with improved scientific methods, they produce about 45–55 quintals of grain/ha under irrigated conditions and 20–25 quintals/ha under rainfed conditions. For safe storage, grain should be cleaned and dried well in sun for a few days so that moisture content of the grain comes down to 10–12%.

Maize

(*Zea mays* L.)

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'.

Maize is grown in almost all the states of India. It occupies an area of about 9.6 million ha which accounts for about 23% of the total area in the continent. It is next to rice, wheat and sorghum with regard to area and production in India.

Maize crop is utilised in many ways like other grain crops. Over 85% of maize produced in the country is consumed as human food. Several food dishes including 'chapatis' are prepared out of maize flour and grains. Green cobs are roasted and eaten by people with great interest. The special variety called the 'Popcorn' the grains of which are characterised by a hard corneous interior structure, are converted into the 'popped' form which is the favourite food for children in cities. It is also a good feed for poultry, piggery and other animals. It ranks below wheat and sorghum but considerably above rice in nutrition. Maize grain contains about 10% protein, 4% oil, 70% carbohydrate, 2.3% crude fiber, 10.4% albuminoides, 1.4% ash. Maize protein 'Zein' is deficient in tryptophane and lysine, the two essential amino acids. Maize grain has significant quantities of vitamin A, nicotinic acid, riboflavin and vitamin E. Maize is low in calcium, fairly high in phosphorus.

Maize crop furnishes huge quantities of green fodder for cattle. Several industries like starch, milling, etc. are based on maize products and by-products. In addition to big industries, several cottage industries are also flourishing on the by-products of maize.

ORIGIN AND HISTORY

The primary centre of origin of maize is considered by most authorities to be the Central America and Mexico, where many diverse types of maize are found. The discovery of fossil maize pollen with other archaeological evidence in Mexico indicates Mexico to be the native home of maize. The studies indicated that maize was a significant crop in Mexico 5,000 years ago and perhaps earlier American Indians grew and selectively improved maize from 3400 BC to 1500 AD.

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 spreads 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.

AREA AND DISTRIBUTION

Maize is one of the world's leading crops cultivated over an area of 197 million ha with production of 1448 million tonnes with a productivity of 5823 kg/ha during 2019 (FAOSTAT). Among the maize growing countries, China has the largest area followed by USA, Brazil, India and Argentina. In respect of production, USA stands first followed by China, Brazil and Argentina. The average maize yield in India is only 3006 kg/ha which is much lower than most of the maize growing countries of the world.

In India, maize is grown over an area of 9.6 million ha with total production of about 28.7 million tonnes. Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh are the leading states growing maize on large scale. Though the maximum acreage and production of maize is in Karnataka but Tamil Nadu has the highest average productivity (7424 kg/ha) followed by Andhra Pradesh (6701 kg/ha) during 2019-20 (<https://www.indiastatagri.com>).

CLASSIFICATION

Maize (*Zea mays*) is an annual plant which belongs to Poaceae family (formerly called Gramineae) 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 the 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 or 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 USA.
3. *Zea mays everta* or 'Popcorn': It possesses exceptional popping qualities. Size of the kernels is small but the endosperm is hard. When they are heated the pressure built up within the kernel suddenly results in an explosion and the grain is turned inside out.
4. *Zea mays saccharata* or 'Sweetcorn': 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 'Softcorn': It possesses a soft endosperm. 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 tunicata* or 'Podcorn': The podcorns are characterised by having each kernel enclosed within a pod or 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.

BOTANICAL DESCRIPTION

Maize (*Zea mays*) belongs to Poaceae (formerly called Gramineae) family. It is a tall annual plant which usually grows to a height of 1 to 3 m or more in some cases. The botanical description of main parts of maize plant is given as follows.

Root System

The root system of maize is fibrous and deep. It is usually well-developed. It consists of (a) seminal roots, (b) crown or 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 or coronal roots*: They arise from the basal portion of the stem. The first four or 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 or aerial roots*: They arise from second, third and sometimes 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 or branch arises at a node. Internodes are somewhat flattened or grooved on the side next to the leaf sheath.

Leaf

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

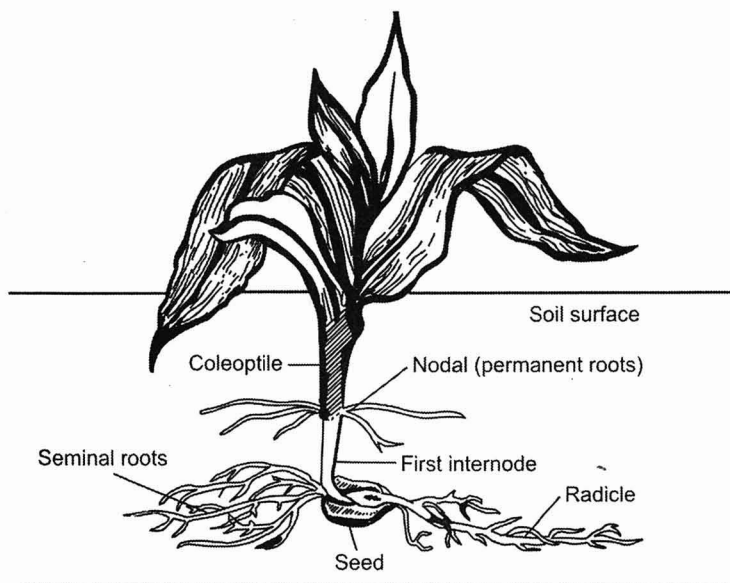


Fig. 3.1: Parts of a young maize plant

internode above the node to which it is attached. The number of leaves varies from 12 to 20. Stomata are present on both the surfaces of the 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 spikelets are 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.

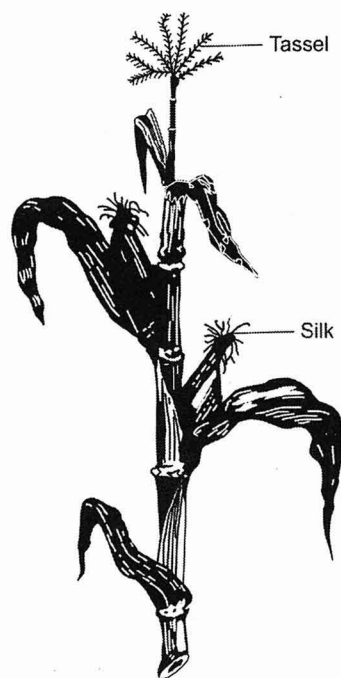


Fig. 3.2: Parts of maize plant showing the pistillate and staminate flowers

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 pollen 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, consists 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 granules. It is surrounded by a layer of aleurone cells. The embryo consists of the plumule, radicle and scutellum.

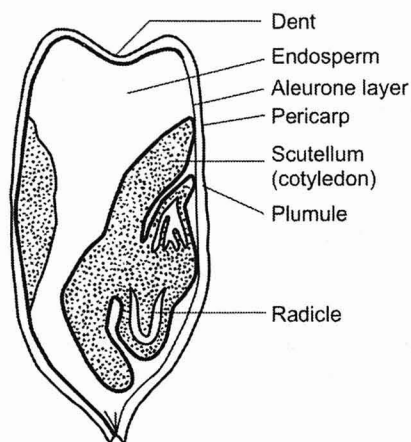


Fig. 3.3: Maize caryopsis

Climatic Requirements

Maize is a warm weather plant. It grows from sea level to 3000 m 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 October, as the climate is warm even in the winter. Maize requires considerable moisture and warmth from germination to flowering. The most suitable temperature for germination is 21°C and for growth 32°C. Extremely high temperature and low humidity during flowering damage the foliage, desiccate the pollen and interfere with proper pollination, resulting in poor grain formation. 50 to 75 cm of well-distributed rain is conducive to proper growth. Maize is very sensitive to stagnant water, particularly during its early stages of growth.

Soil

Maize is best adapted to well-drained sandy loam 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 are very suitable for growing maize crop.

VARIETIES

Maize is a cross pollinated crop, and the cultivars grown in India comprise varieties, hybrids, composites, synthetics. Hybridization is the most potent technique for improving the yield potential of maize, and heterosis vigour has been exploited extensively. Composite varieties are produced by mixing the seed of several photosynthetically outstanding lines and encouraging open pollination to produce crosses in all combinations. Synthetics are produced by crossing a number of lines that combine well with each other, and once synthesized, these are maintained by open pollination in isolation. Unlike hybrids, the seed of composites and synthetics can be used year after year maintaining the production potential undiminished, whereas the hybrids give 15–20% less yield than the F_1 generation seed in the following years. Selection of varieties and hybrids suited to a particular agro-ecological condition, maturity, season and purpose is the key for getting potential productivity of this crop. It is always better to select single-cross hybrids developed and released for a set of climatic conditions. The single-cross hybrids also perform better under the stressed environment. However, in areas where hybrid seed availability cannot be ensured like high altitude and tribal regions, high-yielding, composite varieties can also be grown. Several hybrids and composite varieties of different maturity groups for various purposes have been developed and released in different states of India. Promising hybrids and composites of different maturity groups is given in Table 3.1 and salient characteristics of dominating cultivars are described in Table 3.2. The biofortified varieties and hybrids of maize are given in Table 3.3.

CROPPING SYSTEMS

In the irrigated areas many rotations of crops involving maize are feasible. Crops like wheat, potato, toria, sugarcane, chickpea, berseem, lucerne, barley and oats, etc. can be grown after harvest of maize. Some of the most important cropping systems are given as follows.

- | | |
|----------------------|--------|
| 1. Maize—potato | 1 year |
| 2. Maize—wheat | 1 year |
| 3. Maize—toria—wheat | 1 year |



Fig. 3.4: Maize crop (Courtesy: ICAR-IIMR, Ludhiana) (see Colour Plate 2)

Table 3.1: Promising maize cultivars suitable for *kharif* season

<i>Cultivars released</i>	<i>Cultivars</i>
Released during 2011 to 2020	DMRH 1305, MM 9344, ADV-756, Bisco Champion 61, Karimnagar Makka, HTMH 5402, Pant Sankar Makka 4, DRONA, VMH 4106, P3401, P3544, Central Maize VL 55, GAYMH-1, HTMH 5106, RMH-4620, Pratap Hybrid Maize-3, DKC 9126, UDAY, Mahabeej-1114, Pratap Makka-9, Karimnagar Makka-1, D2244, LAXMI 3636, Palam Sankar Makka 1, CP333, Pratap Hybrid Maize-3, PHM-12, P 3580, CoH (M) 10, HM-13, PMH 6, NMH-731, NMH-1242, CoH (M) 7, CoH (M) 8, CoH (M) 9, DHM 121, GH 0727, Vivek Maize Hybrid 39, 43, 45, 47, 51, 53, Bio 9544, P 1864, Bisco 97 Gold, Shalimar Maize Composite-3, KDM-438, Pant Shankar Makka-1, KDMH-017, NMH-1242, S 6217, Yuvraj Gold, Sun Vaaman, BIO 605, Hishell, KMH-218 Plus, KMH-3426, NMH-731, NMH-803, HM-12, KMH-25K60, KMH 3712, NMH-920, P3441, P3502, NK-30, NK 6240, BIO-9682, CO 6, SMH-3904, P3501, IG 8011, IG 8237, Bisco 855, Bisco 555, Bisco 111, DHM 119, PMH 4, PMH 5, YM-9905, DKC 9099
Released during 2005 to 2010	900M Gold, KMH-22168, DHM-117, DHM-113, DHM-111, DKC 7074 R, Vivek Sankul Makka 35, 37, PAC 740, JKMH-502, NAH-2049, Partap Kanchan-2, WC-236, Chandramani, PMH-3, Pant Sankul Makka-3, Bajaura Makka, Vivek Maize Hybrid 21, 23, 25, 27, 31, 33, Malviya Hybrid Makka-2, HM-8, 9, PAU-352, COH(M) 4, 5, PMH-1, JKMH-1701, PEHM-3, Pratap Makka-4, Pratap Makka-5, Prabal, IC-8306, PMH-2, Pusa Composite-3,4, Birsa Vikas Makka-2, Shalimar KG Maize-1, 2, HM-5, Pratap Makka-3, Bio 9636, DK-984, Vivek Miaize Hybrid-15, Vivek Maize Hybrid-17 (FH-3186), Azad Kamal

Source: ICAR—Indian Institute of Maize Research, Ludhiana

- | | |
|------------------------------------|---------|
| 4. Maize—potato—wheat | 1 year |
| 5. Maize—berseem (Egyptian clover) | 1 year |
| 6. Maize—toria—sugarcane | 2 years |
| 7. Maize—wheat—sugarcane | 2 years |
| 8. Maize—wheat—cotton—berseem | 2 years |
| 9. Maize—senji—sugarcane—cotton | 2 years |
| 10. Maize—wheat—sorghum—sugarcane | 3 years |
| 11. Maize—potato—sugarcane—wheat | 3 years |

Crops like soybean, blackgram, moong, cowpea, etc. are grown mixed with maize. These legume crops are grown in the space between two rows of maize. In Bihar mixed cropping of groundnut with maize is quite profitable. In certain areas maize with pigeonpea is also grown.

FIELD PREPARATION

Maize kernels need a seedbed which is friable, well aerated, moist and weedfree to provide better contact between the seed and the soil. There is no need of preparing an extremely fine seedbed. The first ploughing should be done with soil inverting plough so that at least 20–25 cm deep soil may become loose. It should be followed 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 levelling must not be overlooked. A

Table 3.2: Salient characteristics of promising cultivars of maize

Variety	Zone/state	Year of release	Suitable season	Maturity period (days)	Yield (t/ha)	Remarks
DMRH 1305	NHZ*	2018	Kharif	Early	6.5	High yielding and resistance to major diseases
IMHB 1532	NWPZ and CWZ	2018	Kharif	Short	2.0	Resistant to curvularia leaf spot, moderately resistant to <i>Chilo partellus</i> , suitable for baby corn
DMRH 1301	NEPZ and CWZ	2018	Rabi	94-96	9.9	Moderate resistance to TLB, tolerant to <i>Sesamia</i> and <i>Chilo partellus</i>
CP 838	NWPZ NEPZ PZ CWZ	2018	Rabi	95-100 9.2 8.7 9.2	11.2	High yielding and resistance to major diseases
GAWMH-2	Gujarat	2018	Kharif	Early	6.2	Rainfed, Kharif both high and low fertility
DMRHP 1402	NWPZ and CWZ	2018	Kharif	Short	3.9	Moderate resistant to Fusarium stalk rot, moderately tolerant to <i>Chilo partellus</i>
DMRH-1308	CWZ	2018	Rabi	92-94	9.6	Fairly tolerant to <i>Sesamia</i> and <i>Chilo partellus</i> , suitable for baby corn
Pusa Jawahar Hybrid Maize-1	CWZ	2014	Kharif	95	6.5	Field tolerance to flowering stock rot, and Rajasthan downy mildew (RDM), and stay green plants
Pusa HM8 Improved	PZ	2014	Kharif	95	6.26	High lysine (4.18%), tryptophan (1.06%) and rich in protein quality
Pusa HM-9 Improved (AQH-9)	NEPZ	2017	Kharif	Medium	5.2	QPM Hybrid through MAS, Nutri-rich with enhanced tryptophan and lysine, high protein

(Contd.)

Variety	Zone/state	Year of release	Suitable season	Maturity period (days)	Yield (t/ha)	Remarks
Karimnagar Makka	PZ	2017	Rainfed Kharif	90-95	7.9	Rainfed, Kharif both high and low fertility
Pant Shankar Makka-4	Uttarakhand	2017	Kharif	82-84	4.6	Resistant to leaf spot, moderately resistant to <i>Chilo partellus</i>
Central Maize VL 55	NHZ and PZ	2017	Kharif	95-97	7.6	Moderate resistance against MLB, common rust and PFSR
PMH-10	Punjab	2016	Spring	175-180	11.7	Orange flint kernels
DRONA (KMH-2589)	NWPZ and PZ	2017	Kharif	Long	10.8	Resistant to common rust, PFSR and Charcoal rot
P3544	NWPZ, NEPZ and PZ	2017	Kharif	Long	10.8	Orange yellow, semi-flint
Hema	Karnataka	2016	Spring	120-125	5.6	High yielding and resistant to major diseases
Pratap Makka-9	Rajasthan	2016	Kharif and Rabi	81-87	4.8	Moderate resistant to Fusarium stalk rot, moderately tolerant to <i>Chilo partellus</i>
Palam Shankar Makka-2	NHZ	2016	Kharif	Medium	9.8	High yielding and resistant to major diseases
Partap Hybrid Maize 3	CWZ	2016	Kharif	Early	5.6	High yielding and resistant to major diseases
DKC 9126	NHZ, NWPZ and NEPZ	2016	Kharif	Long	8.9	Yellow orange, semi-flint
BIO 9782	PZ and CWZ	2016	Rabi	Long	10.2	Orange yellow, semi-dent
Karimnagar Makka-1	Telangana	2016	Kharif and Rabi	Medium	9.5	Orange, semi-flint, resistant to post-flowering stalk rot disease
PMH-8	Punjab	2016	Spring	112	8.3	High yielding and resistant to major diseases
PMH 4	NWPZ	2011	Kharif and Spring	Medium	8.3	Yellow-orange, flint, nutrient responsive, resistance to lodging and drought

(Contd.)

Variety	Zone/state	Year of release	Suitable season	Maturity period (days)	Yield (t/ha)	Remarks
PMH-3	NWPZ	2008	Kharif	Long	7.5	Orange, flint
PMH-1	NWPZ	2007	Kharif	Long	6.7	Yellow-orange, flint, resistance to MLB and stalk rots
DHM 121	NEPZ and CWZ	2014	Kharif	Medium	5.4	Yellow, semi-dent and tolerant to moisture stress conditions
DHM-117	PZ	2010	Kharif	Medium	7.8	Orange-yellow, flint
Palam Shankar Makka-1	CWZ		Kharif	Late	5.3	High yielding and resistant to major diseases
CoH (M) 10	PZ	2015	Kharif	Medium	7.2	High yielding and resistant to major diseases
HM-13	NHZ	2015	Kharif	Early	6.6	High yielding and resistant to major diseases
PMH-6	NEPZ	2015	Kharif	Medium	6.3	High yielding and resistant to major diseases
CoH (M) 7	NEPZ and PZ	2014	Kharif	Late	7.8	High yielding and resistant to major diseases
CoH (M) 8	NWPZ, NEPZ, PZ and CWZ	2014	Kharif	Medium	7.1	High yielding and resistant to major diseases
CoH (M) 9	NEPZ and CWZ	2014	Kharif	Medium	6.4	High yielding and resistant to major diseases
DHM-121	NEPZ and CWZ	2014	Kharif	Medium	5.4	High yielding and resistant to major diseases
GH-0727	Karnataka	2014	Kharif	Late	7.5	High yielding and resistant to major diseases
Vivek Maize Hybrid-47	NHZ	2014	Kharif	Early	6.9	High yielding and resistant to major diseases
Vivek Maize Hybrid-53	NHZ	2014	Kharif	Extra early	6.9	High yielding and resistant to major diseases

(Contd.)

Variety	Zone/state	Year of release	Suitable season	Maturity period (days)	Yield (t/ha)	Remarks
Vivek Maize Hybrid-51	CWZ	2014	Kharif	Extra early	5.1	High yielding and resistant to major diseases
Pusa HM4 Improved	NWPZ	2015	Kharif	87	6.42	High lysine (3.62%) and tryptophan (0.91%) and rich in protein quality
Pusa Vivek Hybrid 27 Improved	NEPZ	2015	Kharif	84	4.85	High provitamin-A (5.49 ppm)
Pusa Vivek QPM-9 Improved	NHZ and CWZ	2017	Kharif	Short	5.6	Country's first provitamin-A maize hybrid, Nutri-rich with enhanced Tryptophan (0.74%), Lysine
(2.67%)						
HQPM-1	Across country	2007	Kharif and Rabi	Long	7.5	and high provitamin-A (8.15 ppm) Yellow dent, tolerance to frost/cold, resistance to MLB and common rust
Pusa HQPM-5 Improved	Across country	—	Kharif	Long	6.47	High provitamin-A (6.77 ppm), high lysine (4.25%), tryptophan (0.93%) and rich in high protein quality
Pusa HQPM-7 Improved	Across country	—	Kharif	77	7.45	High provitamin-A (7.10 ppm), high lysine (4.19%), tryptophan (0.93%) and rich in high protein quality

* NHZ (Northern Hill Zone): Jammu and Kashmir, Himachal Pradesh, Assam, Meghalaya, Tripura, Arunachal Pradesh, Nagaland, Manipur, Sikkim

NWPZ (North Western Plain Zone): Delhi, Punjab, Haryana, Delhi, Western Uttar Pradesh

NEPZ (North Eastern Plain Zone): Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal

PZ (Peninsular Zone): Andhra Pradesh, Telangana, Maharashtra, Karnataka and Tamil Nadu

CWZ (Central and Western Zone): Rajasthan, Gujarat, Chhattisgarh and Madhya Pradesh

Source: ICAR—Indian Institute of Maize Research, PAU Campus, Ludhiana

Table 3.3: Biofortified varieties/hybrids of maize

Name	Variety	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
Vivek QPM 9	Hybrid	Rich in lysine (4.19% in protein) and tryptophan (0.83% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	<i>Kharif</i> season in Jammu & Kashmir, Himachal Pradesh, Uttarakhand (Hill region), North Eastern States, Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu	52.0	88	ICAR–Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora
Pusa HM4 Improved	Hybrid	Rich in lysine (3.62% in protein) and tryptophan (0.91% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	<i>Kharif</i> season in Punjab, Haryana, Delhi, Uttarakhand (plains), and Uttar Pradesh (Western region)	64.2	87	ICAR–Indian Agricultural Research Institute, New Delhi
Pusa HM8 Improved	Hybrid	Rich in lysine (4.18% in protein) and tryptophan (1.06% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	<i>Kharif</i> season in Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu	62.6	95	ICAR–Indian Agricultural Research Institute, New Delhi
Pusa HM9 Improved	Hybrid	Rich in lysine (2.97% in protein) and tryptophan (0.68% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	<i>Kharif</i> season in Bihar, Jharkhand, Odisha, Uttar Pradesh (Eastern region) and West Bengal	52.0	89	ICAR–Indian Agricultural Research Institute, New Delhi

(Contd.)

Name	Variety	Biofortified attributes	Adaptation	Grain yield (Q/ha)	Maturity (days)	Developed
Pusa Vivek QPM9 Improved	Hybrid	Country's first provitamin-A rich maize. Rich in provitamin-A (8.15 ppm), lysine (2.67% in protein) and tryptophan (0.74% in protein) in comparison to 1.0-2.0 ppm provitamin-A, 1.5-2.0% lysine and 0.3-0.4% tryptophan in popular hybrids	<i>Kharif</i> season in Jammu & Kashmir, Himachal Pradesh, Uttarakhand (Hill region), North Eastern States, Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu	55.9 [Northern Hills Zone (NHZ)] and 59.2 [Peninsular Zone (PZ)]	93 days (NHZ) and 83 days (PZ)	ICAR-Indian Agricultural Research Institute, New Delhi
Pusa VH 27 Improved	Hybrid	Rich in provitamin-A (5.49 ppm) in comparison to 1.0-2.0 ppm provitamin-A in popular hybrids	<i>Kharif</i> season in Bihar, Jharkhand, Odisha, Uttar Pradesh (Eastern region) and West Bengal	48.5	84	ICAR-Indian Agricultural Research Institute, New Delhi
Pusa HQPM 5 Improved	Hybrid	Rich in provitamin-A (6.77 ppm), lysine (4.25% in protein) and tryptophan (0.94% in protein) in comparison to 1.0-2.0 ppm provitamin-A, 1.5-2.0% lysine and 0.3-0.4% tryptophan in popular hybrids	<i>Kharif</i> season across the country	72.6 (NHZ), 75.1 (NWPZ), 53.5 (NEPZ), 71.2 (PZ), 51.2 (CWZ)	111 days (NHZ), 92 days (NWPZ), 88 days (NEPZ), 98 days (PZ), 91 days (CWZ)	ICAR-Indian Agricultural Research Institute, New Delhi
Pusa HQPM 7 Improved	Hybrid	Rich in provitamin-A (7.10 ppm), lysine (4.19% in protein) and tryptophan (0.91% in protein) in	<i>Kharif</i> season in Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu	74.5	97	ICAR-Indian Agricultural Research Institute, New Delhi

(Contd.)

Name	Variety	Biofortified attributes	Adaptation	Grain yield yield (Q/ha)	Maturity (days)	Developed
IQMH 201 (LQMH 1)	Hybrid	comparison to 1.0–2.0 ppm provitamin-A, 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids Rich in lysine (3.03% in protein) and tryptophan (0.73% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	Kharif season in Jammu & Kashmir, Himachal Pradesh, Uttarakhand, North Eastern States	84.8	101	ICAR–Indian Institute of Maize Research, Ludhiana
IQMH 202 (LQMH 2)	Hybrid	Rich in lysine (3.04% in protein) and tryptophan (0.66% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	Kharif season in Punjab, Haryana, Delhi, Western Uttar Pradesh and plains of Uttarakhand	72.0	96	ICAR–Indian Institute of Maize Research, Ludhiana
IQMH 203 (LQMH 3)	Hybrid	Rich in lysine (3.48% in protein) and tryptophan (0.77% in protein) in comparison to 1.5–2.0% lysine and 0.3–0.4% tryptophan in popular hybrids	Kharif season in Rajasthan, Gujarat, Madhya Pradesh and Chhattisgarh	63.0	90	ICAR–Indian Institute of Maize Research, Ludhiana

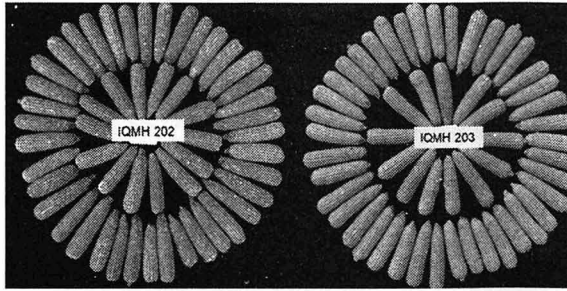


Fig. 3.5: Biofortified hybrids of maize: IQMH-202 & IQMH-203 (Courtesy: ICAR-IIMR, Ludhiana) (see Colour Plate 3)

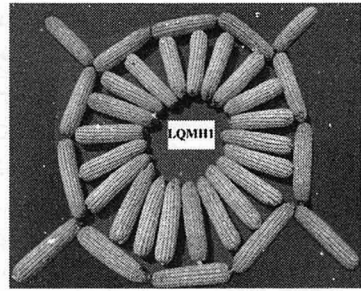


Fig. 3.6: Biofortified maize hybrid LQMH-1 (Courtesy: ICAR-IIMR, Ludhiana) (see Colour Plate 3)

properly levelled and uniformly graded field is required for good water management.

SEED AND SOWING

Certified seeds 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 25%. 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 to four years.

Seed Rate and Spacing

A population of 60000–65000 plants at harvest/ha would be needed to attain maximum yield. It is very important the optimum plant density is maintained in maize, because unlike tillering plants such as rice or wheat, maize cannot compensate for lost space. One seed should be planted at every 20–25 cm in rows 60 cm apart. 10 to 20% more seeds than the desired plant population would be normally required to compensate for various field losses. Based on seed weight and the required plant population/ha, the following calculations have been made:

Hybrids	20–25 kg/ha
Composites	18–20 kg/ha

Seed should be treated with Carbendazim (Bavistin) @ 2.5 g/kg of seed.

Method of Planting

Plant maize across the slope. Sow the seed 3–5 cm deep. 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*: This method is adopted in high rainfall situations and on lands not uniform.
- (b) *Planting in narrow furrows*: This method is adopted in low rainfall areas.
- (c) *Planting in a flat bed with no earthing up*: In normal conditions.
- (d) *Planting on flat bed and earthing-up after 40–50 days of planting*: In areas where there are heavy storms during rainy season.

Time of Planting

Date of planting will differ from place to place. However, the following guidelines have to be observed in choosing the date in the case of *Kharif* sown maize.

Plant two weeks before the onset of monsoon, where irrigation facilities exist. The plants establish themselves well in the field and by the time of heavy rains, the roots go deeper in the soil to give full support to the plants. In addition, most of the diseases and attack of insects start with the onset of monsoon showers. By this time early planted maize plants are able to face and tolerate this adverse weather and environment. As we delay the planting, the maize yields also go down, simultaneously.

In rainfed situations, the sowing of maize is generally done with the onset of rains. To obtain optimum plant stand the sowing of maize should be done by maize planter or seed drill. In absence of these implements, sowing of maize should be done behind the country plough in furrows.

The optimum time of sowing for *Kharif* maize in different agroclimatic regions is as follows.

<i>Agro-climatic region</i>	<i>Sowing time</i>
North-western hills	April to early May
North-eastern hills	First fortnight of March
Peninsular region	May to June 15
Indo-gangetic plains	June to 15 July

MANURES AND FERTILISERS

Manures and fertilisers both play important role in the maize cultivation. A liberal quantity of bulky manures should be applied in the field if available. Add 10 to 15 tonnes 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.

Hybrids and composite varieties of maize exhibit their full yield potential only when supplied with adequate quantities of nutrients at proper time. A crop of maize yielding about 14 tonnes of dry matter (both grain and stover) takes up about 161 kg N, 34 kg P and 110 kg K/ha. The exact quantity of the fertiliser 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 120 kg N, 60 kg P_2O_5 and 40 kg K_2O /ha for hybrids and 80 kg N and 30 kg P_2O_5 and 20 kg K_2O /ha for composites.

TIME AND METHOD OF FERTILISER 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 tasseling stage. In general, it would be advisable to apply the total quantity of P and K and one-third of nitrogen at planting and split up the remaining two-thirds of N in two equal doses, one at knee high stage (about 30–35 days after planting) and the rest at tasseling. In case of nitrogenous fertilisers 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 fertiliser application is also very important. The basal dose should be placed in the soil. This can be done with the help of fertiliser drill and if it is not possible use a funnel attachment behind the plough. The fertiliser should be placed about 3–5 cm to the side and 3–5 cm 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/ha 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 proceeds 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.

Potash: Potassium deficiency results in a characteristic pattern of leaf discolouration by small whitish-yellow spots, followed by scorching or browning or 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 susceptible both to excess water and moisture stress. Never allow water to stand in a maize field at any stage of its growth. Water stagnation

even for six hours continuously and sufficiently damage the crop. Maize can tolerate heavy rains, provided water does not stand in the field for long periods. Therefore, drain away excess water by making a drain of adequate capacity at the lower end of the field.

A good crop of maize requires about 460 to 600 mm of water during its life cycle. Do not allow maize plants to wilt due to water shortage at any stage of the life cycle. Tasseling to silking stage is critical. At this stage water shortage even for 2 days can reduce maize yields by about 20%. The same for 6–8 days can pull down the yield by 50%. Irrigate the crop whenever it is needed.

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 fertiliser use efficiency. Losses through weed competition in early stages cannot be offset by keeping the field weed free later. In case the weeds are not brought under control at right time, there is 50–60% reduction in yield. Maize crop is infested with grassy and broad-leaved annual weeds. Among grassy weeds, *Echinochloa colonum*, *Enhinochloa crusgulli* (sawan), *Dactyloctenium aegypticum* (makra), *Elusine/nd/ca* (kodo), *Setaria glauca* (banra), *Cynotion dactylon* (doob), *Phragmites karka* (narkul), *Cyperus rotundus* (motha), *Sorghum halepanse* (banchari) are common.

The broad-leaved weeds are *Celosia argentia* (chilimil), *Commelina benghalensis* (kankoua), *Phylanthus niruri* (hulhul), *Solanum nigrum* (makoi), *Amaranthus viridis* (chaulai) and *Podrtulaca oleraceae* (naunia).

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 used in maize crop.

Chemical Weed Control

The application of pre-emergence atrazine @ 0.5–1.0 kg/ha followed by one hand weeding at 25–35 DAS gives good weed control in maize (Table 3.4). However, due to increased labour prices, the hand weeding can be replaced with application of tembotrione (120 g/ha) or topramezone (25 g/ha) or 2,4-D Dimethyl Amine salt @ 0.5 kg/ha for weed management in maize (Table 3.4). Recently, Tembotrione (120 g/ha) + Atrazine (750 g/ha) or Topramezone

Table 3.4: Herbicidal options for weed management in maize

Herbicide	Dose (kg/ha)	Time of application	Targeted weed species
Atrazine 50% WP	0.5–1.0 kg	Pre-emergence (0–3 days after sowing of crop)	<i>Trianthema monogyna</i> , <i>Digera arvensis</i> , <i>Echinochloa</i> spp, <i>Eleusine</i> spp, <i>Xanthium strumarium</i> , <i>Brachiaria</i> sp, <i>Digitaria</i> sp, <i>Amaranthus viridis</i> , <i>Cleome viscosa</i> , <i>Polygonum</i> spp
Tembotrione 42% SC	120 g	20–35 days after sowing of crop	<i>Trianthema potulacastrum</i> , <i>Echinochloa</i> sp, <i>Bracharia</i> sp
Topramezone 33.6% SC	25 g	20–35 days after sowing of crop	<i>Trianthema potulacastrum</i> , <i>Echinochloa</i> sp, <i>Bracharia</i> sp
2,4-D Dimethyl amine salt 58 SL	0.5 kg	20–35 days after sowing of crop	<i>Trianthema monogyna</i> , <i>Amaranthus</i> sp, <i>Tribulus terresteris</i> , <i>Boerhaavia diffusa</i> , <i>Euphorbia hirta</i> , <i>Portulaca oleracea</i> , <i>Cyperus</i> sp
For minimum tillage (Zero tillage)			
Paraquat 24% SL	0.2–0.5 kg	Before sowing of the crop in zero-tillage	<i>Cyperus rotundus</i> , <i>Commelina benghalensis</i> , <i>Trianthema monogyna</i> , <i>Amaranthus</i> sp, <i>Echinochloa</i> sp
Paraquat 24% SL	0.2–0.5 kg	Post-emergence directed inter-row application at 2–3 leaf stage of weeds	<i>Cyperus iria</i> , <i>Cyperus rotundus</i> , <i>Commelina benghalensis</i> , <i>Amaranthus</i> sp, <i>Echinochloa</i> sp, <i>Trianthema monogyna</i>

(25.2 g/ha) + Atrazine (750 g/ha) at 15 days after sowing suggested as new option for weed management in maize.

For zero-tilled maize, application of paraquat dichloride 0.2–0.5 L/ha as pre-plant application before sowing of maize kills the weed in the field and prevents the regrowth of rice stubbles. The paraquat can also be used in post-emergence directed inter-row application at 2–3 leaf stage of weeds where care should be taken that no droplets during application shall touch the maize crop plants. Pre-emergence application of paraquat 24% @ 1.0 L/ac to arrest re-growth of paddy stubbles followed by atrazine @ 1.0 kg/ac in 200 L water. Combination of paraquat and atrazine was also found to give effective weed control.

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 as follows.

Seed Rot and Seedling Blight

These diseases are caused by several fungi or fungus-like micro-organisms, mainly *Pythium ultimum*, *Fusarium verticillioides*, other *Fusarium* spp. and

Penicillium oxalicum (on sweet corn). These fungi may survive on corn crop residue or in soil and are carried on seed. The diseases are more prevalent in poorly drained and excessively compacted or cold, wet soils. Planting poor quality seed increases seed rot and seedling blight as does planting seed too deep in wet, heavy soil.

Control Measures

- Use quality seed and practise optimum water management practices, especially avoiding overwatering the first few weeks after planting.
- Crop rotation and destroying old corn stalks are helpful in controlling diseases.

Black Bundle Disease

This disease is caused by *Cephalosporium maydis* and *Cephalosporium acremonium*. These pathogens survive in soil, plant debris and seed. The disease is favoured by post-flowering water stress symptoms. *Cephalosporium maydis* is primarily soil-borne and may infect young maize plants more readily than other plants through roots or mesocotyl. In case of *C. acremonium* only vascular bundles get blackened.

Control Measures

- Use quality seed and practise optimum water management practices, especially avoiding overwatering the first few weeks after planting.
- Use of resistant varieties.
- Crop sanitation and crop rotations help in reducing the occurrence of disease.
- Avoiding water stress at flowering.

Bacterial Stalk Rot

Stalk rot is caused by the bacterium *Erwinia chrysanthemi* Pv. *Zee*. It survives itself on diseased debris. The bacterium infects the plant, especially at the collar, at any stage of its growth period. The organism dissolves the middle lamella of the cell walls, as a result the tissues disintegrate and the plant collapses to the ground. Basal internodes become soft, discoloured and give a bad fermenting smell.

Control Measures

- Use of resistant varieties.
- Select well-drained field or arrange proper drainage to avoid water-logging.
- Avoid injury on the plants at the time of weeding and top dressing of urea.
- Bleaching powder should be applied along the rows @ 20–25 kg/ha.

Pythium Stalk Rot

Partial infection of any lower internode is the characteristic symptom of the disease. Infected plants become soft and at this point the plants get twisted and topple over the ground. It becomes serious if plant population is over 75000 plants/ha and water accumulates during knee high to pre-flowering

stage of crop growth. For its control, apply Captan in poorly drained pockets of the field along the rows @ 150 g/100 L of water or Metalaxyl + Mancozeb @ 300 g/100 L water.

Sugarcane Downy Mildew

This disease is caused by *Poronosclerospora sacchari*. Long, rather broad, yellowish or whitish strips appear on or up to the upper leaves of the plant. Whitish coarse fungus growth is more apparent on affected leaves and may spread up to tassels. In severe cases, infected plants remain stunted and their leaves look pale yellow in colour.

Control Measures

- Grow tolerant varieties like Tarun, Naveen, Kanchan, etc.
- Rogue out infected plants which can be used as fodder.
- Use of systemic fungicide Metalaxyl 35% WS as wet slurry seed dresser @ 0.75–1.0 kg/100 kg seed for effective control of this disease.

Brown Stripe Downy Mildew

This disease is caused by *Sclerophthora rayssiae*. Characteristic symptoms are chlorotic to straw coloured stripes on the lower leaves and after sometime on upper leaves also. Fine cottony growth of the fungus can be seen on the affected leaf surface during morning hours.

Control Measures

- Brown stripe downy mildew can be controlled by use of seed dresser with Metalaxyl-M 31.8% ES @ 2.4 ml/kg seed or Metalaxyl 35% WS @ 0.75–1.0 kg/100 kg seed.
- It can also be controlled by spraying of 0.1% Azoxystrobin 18.2% w/w + Difenoconazole 11.4% w/w SC.

Maydis and Turcicum Leaf Blights

It is caused by *Drechslera maydis*. In maydis leaf blight, individual spots are greyish, tan, up to one and a half inches in length, oval-shaped with straight zonations. Turcicum leaf spots are greyish green or straw coloured and boat-shaped. They are comparatively fewer in number and larger in size than those of maydis.

Control Measures

- Spray of 0.1% Kresoxim-methyl 44.3% SC for its effective control.

Banded Leaf and Sheath Blight

This disease is caused by *Rhizoctonia solani*. Water-soaked, straw-coloured necrotic lesions alternating with dark brown bands develop on basal leaf sheaths. Lesions enlarge and coalesce with each other. Later, sclerotia develop on diseased sheaths, husk and cobs. In severe cases, developing ears are completely damaged and dry up prematurely with cracking of husk.

Control Measures

- Spray 250 ml Amistar Top 325 SC (azoxystrobin + difenoconazole) in 500 litres of water per hectare at disease appearance. If needed, repeat the spray at 15 days interval.

INSECT PESTS

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

Stem Borer

Stem borer is a very serious pest of maize. The damaging stage of the pest is larvae. The eggs hatch in about two to five days. The freshly hatched caterpillars migrate towards the central shoot where they first feed on the tender leaves for sometime. Later on, they bore into top internode and move downwards. In case of younger plants, the growing point and base of central whorl gets badly damaged resulting into the drying up of the central shoot. It is commonly known as 'dead heart'. This condition, however, does not appear when the plant is attacked in the later stages.

Control Measures

Adopt the following integrated control measures:

1. Kill the borer larvae hibernating in plant remnants like stubbles, stalks, cobs and cores. Plough up the fields after harvesting the maize crop, collect the stubbles and destroy them. Use maize stalks, cobs and cores by the end of February. Chop the remaining stalks; if any, for subsequent use. For seed, keep only healthy cobs, free from borer attack.
2. Remove and destroy the plants showing severe borer injury, while hoeing the crop.
3. Use trichocards twice having one lakh eggs of *Corcyra cephalonica* parasitized by *Trichogramma chilonis* per hectare. First release on 10 days old crop and second 7 days after the first release. Cut trichocards into 40 strips, each having approximately 1000 parasitized eggs. Staple these strips uniformly on the underside of the central whorl leaves in evening hours.
4. Spray the crop 2–3 weeks after sowing as soon as borer injury to the leaves is noticed with 75 ml chlorantraniliprole 18.5 SC (Coragen) using 150 litres water.

Fall armyworm

Fall armyworm (*Spodoptera frugiperda* J E Smith) is an invasive pest native to the America and is predominantly a pest of maize but is reported to attack more than 100 crop species. In India, fall army worm (FAW) was first reported in May 2018 in Karnataka and has spread across all maize growing states of our country. The larvae of FAW appear in shades of green, olive, tan and grey with four spots in each abdominal segment. The larva can be identified by

predominant white-coloured inverted Y-shaped mark on the head and presence of four spots arranged in square pattern at the tail end. The young larvae feed by scrapping the leaf surface making papery windows. The bigger larvae feed voraciously on the central whorl leaves causing round to oblong holes and produce a large amount of faecal matter.

Control Measures

Adopt the integrated pest management measures:

1. Sow the crop at recommended time only. Prefer single cross maize hybrids for growing. Choose cultivars with tight husk cover, especially for sweet corn
2. Deep ploughing after harvest of crop to open up the soil to expose pupae to sunlight and predators. If zero tillage is practiced, spread neem cake @ 500kg/ha. Maintain fields weed free and follow balanced fertilizer application.
3. Plan for maximizing plant diversity by intercropping of maize with suitable pulse crops like pigeon pea, black gram, green gram. Plant Napier grass in the border rows to act as trap crop.
4. Avoid staggered sowing of maize in adjacent fields to minimize spread of this pest.
5. Spray the crop with chlorantraniliprole 18.5 SC (Coragen) @ 0.4 ml per litre water or spinetoram 11.7 SC (Delegate) @ 0.5 ml per litre or emamectin benzoate 5 SG (Missile) @ 0.4 g per litre using 300 litres of water per hectare, for crop up to 20 days old. Thereafter for older crop, the amount of water used per hectare needs to be increased up to 500 litres with corresponding increase in dosage of above insecticides. For effective control, direct the nozzle towards the whorl.

Pink Stem Borer

It is a polyphagous pest and is not so serious in north as in south India. It generally attacks the crop in the late stage when cob formation starts in the field. The newly hatched larvae, first feed on the tender leaves and then bore towards the central shoot. This results in drying up of the central shoot and creation of 'dead heart'.

Control Measures

Spray 2 litres Ekalux 25 EC (quinalphos) in 800–1000 litres of water per hectare with hand operated knapsack sprayer.

Shoot Fly

It is a very serious pest of maize in south India. In north India, however; maize crop is not affected much except in the spring season in Tarai area. The attack is maximum when the crop is in seedling stage. Within two days or so eggs hatch and the tiny maggots creep down under the leaf sheaths till they reach the base of the seedling. After this they cut the growing point or central shoot which result in the formation of characteristic dead hearts.

Control Measures

For effective control of this pest, spray one litre of Ekalux (quinalphos) in 500 litres of water per hectare with hand-operated knapsack sprayer.

Maize Leaf Roller

Damage is caused by the caterpillar which is glossy green in colour and becomes pink when fully grown up. The larvae after emergence wander on the tender leaves. They fold the leaves by silking threads and hide themselves inside the rolled leaves. The surface of the attacked leaf becomes white and papery in appearance.

Control Measures

Spray the crop with 50 ml flubendiamide 48 SC (Fame) or 425 g of cartap hydrochloride 75 SG (Mortar) or 2.5 litre of clorpyrifos 20 EC (Coroban/Durmet/Force) in 700–750 litres of water per hectare.

Kharif Grass Hopper

Kharif grass hopper generally does not cause much damage to maize crop. However, in a favourable season, it may prove very harmful and leaves nothing on the plant except stem and midribs of leaves. Both adult and nymph stages of this pest are responsible for the damage. Adults are green or dry grass coloured.

Control Measures

Grass hopper can be controlled to some extent by hot weather cultivation, which exposes their eggs to hot sun and natural enemies. Uncultivated area provides a proper place for egg laying, therefore, it should be reduced as much as possible. For effective control of this pest, spray one litre of Ekalux (quinalphos) in 500 litres of water per hectare with hand-operated knapsack sprayer.

Cut Worm

The larvae of this pest cut the seedlings at the ground level. Caterpillars are grey in colour. They live in soil during day and feed at night. The adults of cut worm may be trapped on light source and may be killed later.

Control Measures

- Spray of Neem oil, Nimbecidine or Achook 2.5 litre/ha mixed with 0.1% detergent powder can be used for its management of jassids or whitefly or aphids.
- Spray whenever insect population crosses economic threshold level with thiamethoxam 25 WG (Actara) @ 100 g or imidacloprid 200 SL (Imidacel/Confidor) @ 100 ml/ha.

White Grub

This pest is very serious in sandy soils. The larvae are white C-shaped and feed on the roots of the plants. In areas where it is a problem, damage may result in complete failure of crop.

Control Measures

- Use well decomposed organic manures.
- Crop rotation with other suitable crops like jowar/sorghum and bajara/pearl millet.
- Take up early sowing if irrigation facility available.
- Seed treatment with chlorpyrifos 20 EC @ 6.5–12.0 ml/kg or imidacloprid 17.8 SL @ 2.0 ml/kg seed.
- Furrow application of insecticides such as, thiamethoxam 25 WS @ 1.9 litres/ha or fipronil 5FS @ 2.0 litres/ha.
- Drench the root zone of crop with chlorpyrifos 20 EC @ 4.0 liter/ha or Ecalux (quinalphos 25EC) @ 3.5 liter/ha three weeks after the adult emergence.

HARVESTING AND THRESHING

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

Remove the husk from the cobs and then dry them in 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/ha in case of hybrids and 45–50 quintals in case of composites under irrigated conditions. In case of rainfed crop yield levels are about 20–25 quintals for hybrids and 15–20 quintals for composites.

RABI/MAIZE

In recent past, maize became popular in peninsular and eastern India. *Rabi* maize favorably responds to better crop management resulting into high yield. The *Rabi* yield of maize realized in India can be compared with those currently obtained in USA, Europe and other developed countries. The top *Rabi* maize producing states in India are Bihar, Tamil Nadu, West Bengal, Andhra Pradesh and Telangana (Table 3.5). West Bengal has the highest productivity (7362 kg/ha) followed by Tamil Nadu (6998 kg/ha), Andhra Pradesh (6992 kg/ha) and Telangana (6502 kg/ha). Some important cultivars suitable for *Rabi* cultivation in various agro-ecologies are presented in Table 3.6.

Table 3.5: Rabi maize area, production and productivity scenario in India during 2018-19

State/UTs	Area ('000 ha)	Production ('000 t)	Yield (kg/ha)
Bihar	446.2	2018.6	4524
Tamil Nadu	221.6	1550.9	6998
West Bengal	210.6	1550.6	7362
Andhra Pradesh	162.0	1132.7	6992
Telangana	117.0	760.7	6502
Maharashtra	218.5	400.6	1833
Karnataka	108.3	365.8	3377
Gujarat	98.7	253.0	2563
Uttar Pradesh	59.0	133.0	2254
Madhya Pradesh	11.0	41.9	3809
Jharkhand	5.9	11.3	1905
Odisha	2.9	7.5	2610
Others	34.7	74.8	2154
All India	1696.6	8301.5	4893

Source: DACNET, MoHFW, GoI, 2020

Table 3.6: Rabi maize cultivars suitable for various agro-ecologies in India

Maize type	Cultivars
Normal rabi maize	CP. 999, CP. 838, HTMH 5108, Top Class, GK 3150, 3155, LG 3404, 3405, DMRH 1301, DMRH 1308, Bisco X 5129, P3533, RJ-2020, SHIATS Makka 3, PratapMakka-9, Karimnagar Makka-1, BIO 9782, Dragon, KMH-7148, NMH-713, Bumper, P3522, Bisco x 1, DKC 9081, PKVM-Shatak, KMH-22168, DHM-111, 113, 117, HM- 5, 10, 11, Pinnacle, DH1, NAH-2049, Sharadmani, Bio-22027, 30B07, COH(M) 4, Buland, Super Kohinoor

The key reasons for realization of higher productivity of *rabi* maize in India are as follows:

- 1. Crop duration:** Longer crop duration of 130–160 days compared to 90–120 days of *kharif* season maize. The long duration favours by prevailing low temperature conditions during winter season and as the duration has the positive link with yield and thus *rabi* maize gives higher yield over rainy season maize.
- 2. Irrigation:** *Rabi* maize is grown under assured irrigated conditions while *kharif* maize is mostly grown under rainfed environment. There is also no high and low moisture stress which is often seen in *kharif* season due to drought and waterlogging.
- 3. Long duration cultivars:** The medium to long duration single cross hybrid are being grown in maize that has higher productivity than the early to medium duration hybrids preferred in *kharif* season.
- 4. Lesser pest and disease infestation:** The *rabi* maize due to better growing conditions has lesser pest and disease incidence compared to *kharif* maize.

5. **Higher plant density:** The *rabi* maize is being grown with around 80 to 90 thousands plants per ha which are much higher than *kharif* maize of 60 to 70 thousands/ha and thus enables to harvest higher yield.
6. **Lesser weed infestation:** The multiple flushes of weeds cause significant reduction of crop yield in *kharif* season while the weed pressure is lesser under *rabi* season.
7. **Optimum use of input and higher input use efficiency:** Due to better growing environment farmers applies the best and optimum input for maximization of profit in winter season maize cultivation. This gives higher yield and input use efficiency in this favourable growing environment.

PACKAGE OF PRACTICES FOR INCREASING PRODUCTIVITY

Choice of Variety

The success and the level of profit from *Rabi* crop depend to great extent on the choice of the maize hybrid/composite to be grown. Open pollinated varieties traditionally grown in *Kharif* are not likely to give high-yield in *Rabi*. Farmers should therefore be encouraged to sow only high-yielding hybrids suitable for *Rabi* season. The use of F1 hybrid seed is essential for realising high-yield. The maize hybrid and composites recommended for *Rabi* cultivation are listed in Table 3.6.

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 India drops rather sharply. This results in delayed germination and plant growth receives a major setback.

Hence, any marked delay in sowing is likely to result in lower yield. Also in late sown crops, there is an increased incidence of common rust, which is not a serious concern in timely sown crop. Generally, sowing should be completed by the end of October. 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 is received and the seedbed remains warm.

Fertiliser Application

The efficiency of nitrogen utilisation is better in *Rabi* than in *Kharif* primarily because of better water management and lower leaching losses, with better fertiliser response, it should be possible to substantially reduce the cost of production of every tonne of maize produced in *Rabi*.

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

The quantity of fertilisers to be applied depends mainly on soil fertility and the preceding field management. In general, a balanced application of 120:60:40 kg/ha of NPK is recommended.

One-fourth of nitrogen and the total quantity of phosphorus and potash should be applied before sowing. The rest of the nitrogen should be applied in two equal doses. Half of the total nitrogen (60 kg N/ha) should be top-dressed at knee-high stage, while the rest of the nitrogen should be applied with the emergence of the flag-leaf. Nitrogen in form of urea should be carefully applied 15–20 cm away from the plants to avoid any leaf injury.

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

Seed Rate and Spacing

A population of 90,000 plants/ha at harvest is desirable for realising high grain yield in *Rabi*. A spacing of 60 cm between rows and 18 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 seedling emergence. In addition, 1 or 2 intercultivations 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 irrigations 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.

Fall Armyworm (FAW)—an invasive pest of maize

Fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) is new pest of maize which has the potential to cause substantial damage. FAW is native to tropical and subtropical regions of America. FAW was first noticed in Africa in 2016. In Brazil and other South American countries, FAW can reduce maize yield up to 57% depending upon the crop season and hybrids used. The incidence of FAW in India was first observed in Karnataka in May, 2018. Within one year, FAW has spread almost all over India which threatens the national food security and presents a major challenge to maize growers. Real time detection and spread of FAW is important for its effective control. Plantix (Germany) has developed a FAW Live Tracking System which capture of FAW in real time based on report of field workers and farmers and depicts in the tracking map. Integrated pest management (IPM) which encompasses cultural, mechanical, biological and need-based chemical methods adopted appropriately based on crop stage and level of infestation, is the way forward to fight against his internationally notorious pest.

Source: Fight Against Fall Armyworm (2019), ICAR-Indian Institute of Maize Research, Ludhiana

Cropping Systems

Short duration varieties of pulses (peas, rajmash and other beans), most vegetables, and oilseed crops (soybean, linseed) can be successfully intercropped in maize. While the yield of maize under intercropping is in no way lower than the yield of pure maize, the intercrop is a bonus. It is also possible to intercrop wheat in maize. Short-statured varieties of maize perform better under intercropping. This practice is particularly desirable under delayed sowing following late harvest of rice.

The following crops are recommended for intercropping with maize:

State	Crops recommended for intercropping
1. North-Western region (Punjab, Haryana, Delhi and Western UP)	Pea, rajmash, lentil
2. North-Eastern region (Bihar, Eastern UP, Odisha, West Bengal and NE region)	Pea, rajmash, potato, lentil, bakla and onion
3. Southern region (Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu)	Fenugreek (<i>methi</i>), corriander, sunflower and cluster beans
4. Central region (Rajasthan, MP, and Gujarat)	Pea, lentil, onion, garlic and <i>methi</i>

YIELD

By adopting package of practices as indicated above, it is possible to obtain 50–60 quintals of grain in case of hybrids and 40–45 quintals of grain in case of composites.

SPECIALTY MAIZE TYPES

Other than grain, maize is also cultivated for various other purposes. The various speciality maize types are: Quality protein maize (QPM), baby corn, sweet corn, pop corn, etc. In India, QPM, baby corn and sweet corn are becoming popular among farmers and also recommended for cultivation. Specialty maize cultivars and their salient attributes/characteristics recommended for growing in various agro-ecologies in India is presented in Tables 3.7 and 3.8.

Table 3.7: Specialty maize cultivars recommended for growing in various agro-ecologies in India

Quality protein maize (QPM)	IMHQPM1530, Pusa HM-8 Improved, Pusa HM-9 Improved, Pusa HM-4 Improved, PusaVivek QPM-9 Improved, Pratap QPM Hybrid-1, HQPM-4, HQPM-7, Vivek QPM 9, HQPM-1,4, 5, 7, Shaktiman-1, 2, 3, 4, 5
Baby corn	IMHB1539, IMHB 1532, Central Maize VL Baby Corn 2, HM-4, VL Baby Corn, COBC-1, G5414
Sweet corn	ASKH-1, Shalimar Sweet Corn-1, VL Sweet corn-1, 2, Hi Brix 39, Hi Brix-53, Hi-brix-39, CANDY, Sugar 75, HSC 1, Win Orange, Madhuri, Priya
Popcorn	IMHP 1535, 1540, DMRHP 1402, BPCB-6, Shalimar Pop Corn-1, Jawahar Pop Corn-11, Pearl Popcorn, VL Amber Pop Corn

Quality protein maize: As more than 85% of the maize is used directly for food and feed, the quality has a great role for food and nutritional security in the country. In this respect, discovery of Opaque-2 (O2) and floury-2 (F2) mutant had opened tremendous possibilities for improvement of protein quality of maize which later led to the development of "Quality protein maize (QPM). QPM which is nutritionally superior as compared to normal maize is the new mantra to signify its importance not only for food and nutritional security but also for quality feed for poultry and animal sectors. Quality Protein Maize has specific features of having balanced amount of amino acids with high content of lysine and tryptophan and low content of leucine & isoleucine. The balanced proportion of all these essential amino acid in quality protein maize enhances the biological value of protein. The biological value of protein in QPM is just double than that of normal maize protein which is very close to the milk protein as the biological value of milk and QPM proteins are 90 and 80% respectively. Whereas it is less than 50% in normal maize protein. The production technology of QPM is same as of normal grain maize except isolation as to maintain the purity of QPM, hence it should be grown in isolation with normal maize.

Baby corn: Baby corn is a young finger like unfertilized cobs with one to three centimeters emerged silk preferably harvested within 1–3 days of silk emergence depending upon the growing season. It can be eaten raw as salad and in preparation of different recipes such as chutney, pakora, mix vegetables, pickles, candy, murabba, kheer, halwa, raita, Chinese preparations, etc. The

Table 3.8: Salient attributes of promising varieties of specialized maize

Variety	Zone/state	Year of release	Suitable season	Maturity period (days)	Yield (t/ha)
QPM					
Pusa HM-8 Improved	PZ	2017	Kharif	90–95	6.3
Pusa HM-9 Improved	NEPZ	2017	Kharif	85–90	5.2
Pusa HM-4 Improved	NEPZ	2017	Kharif	85–90	5.2
Pusa Vivek QPM-9	NHZ, CWZ	2017	Kharif	80–85	5.6
Shaktiman-5	NEPZ	2018	Kharif	80–85	5.5
			Rabi	95–100	8.0
Shalimar QPMH-1	J & K	2019	Kharif	135	6.0
Sweet Corn					
Shalimar Sweet Corn-1	J & K, NHZ	2019	Kharif	90–95	6.5
VL Sweet Corn Hybrid-2	NHZ, NWPZ	2019	Kharif	90–95	10.8
CL Sweet Corn-1	CZ	2016	Kharif	90–95	8.6
Pusa Super Sweet Corn-1	NHZ, NWPZ, NEPZ and PZ	2015	Kharif	75	9.3
Pusa Super Sweet Corn-2	NHZ, NWPZ, NEPZ and PZ	2017	Kharif	77	9.5
Baby Corn					
IMHB1539	NHZ	2018	Kharif	Short	1.3
IMHB1532	NWPZ, CWZ	2018	Kharif	Short	2.0
Vivek Hybrid 27	NHZ, CWZ	2017	Kharif	95–97	2.2
Popcorn					
DMRHP-1402	NEPZ, CWZ	2018	Kharif	75–77	3.9
Shalimar Pop Corn-1	NHZ, NWPZ, NEPZ, PZ	2017	Kharif	95–100	3.9
BPCH-6	NHZ, CWZ, PZ, NEPZ	2015	Kharif	Early	3.9

Source: ICAR—Indian Institute of Maize Research, Ludhiana; Sharma et al, 2020

desirable size of baby corn is 6 to 11 cm length and 1.0 to 1.5 cm diameter with regular row / ovule arrangement. The most preferred colour by the consumers/ exporters is generally creamish to very light yellow. Baby corn is nutritive and its nutritional quality is at par or even superior to some of the seasonal vegetables. Besides proteins, vitamins and iron, it is one of the richest sources of phosphorus. It is a good source of fibrous protein and easy to digest. It is almost free from residual effects of pesticides. It can be cultivated round the year therefore, three to four crops of baby corn can be taken in a year. Cost of cultivation of baby corn in India is lowest in the world, therefore, India can become one of the major baby corn producing country. It has great potential both for internal consumption and export.

In general, the cultivation practices of baby corn are similar to grain crop except (i) higher plant population, (ii) higher dose of nitrogen application because of higher plant population, (iii) preference for early maturing single cross hybrid and (iv) harvesting within 1–3 days of silk emergence.

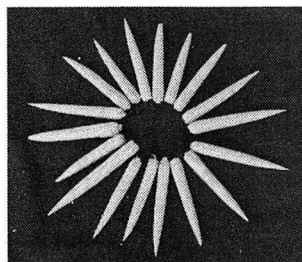


Fig. 3.7: IMHB-1539 hybrid of baby corn (*Courtesy:* ICAR-IIMR, Ludhiana) (see Colour Plate 3)

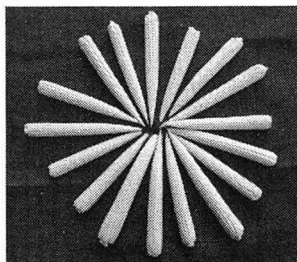


Fig. 3.8: LBCH-3 hybrid of baby corn (*Courtesy:* ICAR-IIMR, Ludhiana) (see Colour Plate 3)

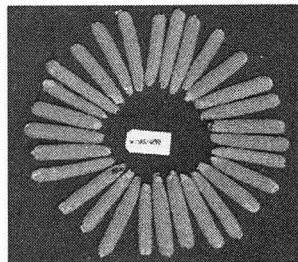


Fig. 3.9: LPCH-2 hybrid of popcorn (*Courtesy:* ICAR-IIMR, Ludhiana) (see Colour Plate 3)

Sweet corn: Sweet corn is one of the most popular vegetables in the USA, Europe and other advanced countries of the world. It is a very delicious and rich source of energy, vitamins C and A. It is eaten as raw, boiled or steamed green cobs/grain. It is also used in preparation of soup, salad and other recipes. It is becoming very popular in urban areas of country, therefore, its cultivation is remunerative for peri-urban farmers. Besides green cobs, the green fodder is also available to the farmers for their cattle. Generally sweet corn is early in maturity. It is harvested in 70–75 days during kharif season. Green cobs are harvested after 18–20 days of pollination during kharif but the duration may vary season to season. At the harvest time the moisture is generally 70% in the grain and sugar content varies from 11 to more than 20%.

Sweet corn is generally dull yellow and white but dull yellow colour is preferred. Its picking should be done in the morning or evening. Green cobs should be immediately transported to the cold storage in refrigerated trucks to avoid the conversion of sugar to starch. It loses flavor if kept in high temperature after picking. Sweet corn with high sugar content should not be planted when temperature is below 16°C.

Popcorn: Popcorn is one of the common snack items in many parts of the world, particularly in cities and is liked because of its light, porous and crunchy texture. The popcorn flour can also be used for preparing many traditional dishes. It is consumed fresh, as it has to be protected against moisture absorption from the air. It is hard endosperm flint maize. Kernels of popcorn are very small and oval/round in shape. When heated at about 170°C, the grains swell and burst, turning inside out. Quality of popcorn depends on popping volume and minimum number of non-popcorn.

Maize as a Candidate Crop for Diversification of Rice-Wheat System in North Western India

The adverse environmental, economic and health impacts of rice-wheat cropping system in the north-western Indo-Gangetic plains calls for immediate diversification of this cropping system through introduction of more sustainable cropping system. Looking into the future scenario of water availability for rice cultivation in states like Punjab and Haryana, maize is a

potent alternative for diversification during Kharif and can replace with some portion of water guzzling rice cultivation. Further, short duration green gram (moong) duration can fit well in maize based cropping system ensuring additional income to the farmers and additional fertility to the soil.

Why maize replace rice?: Maize has almost one-third water requirement of rice, with cropping duration (100–110 days) less than rice (120 days). One kg of maize grain requires 800–1000 lt of water against 3000–3500 litres of water for one kg rice production. As far as energy consumption is concerned, maize production consumes only 278 kwh/ha electricity as against that of rice with 2925 kwh/ha. Similarly, maize (900–1400 kg CO₂ eq/ha) has very less global warming potential (GWP) as compared to rice (3700–4700 kg CO₂ eq/ha). Rice production gives nearly 300–400 kg CO₂ eq/ha due to methane emission which is not associated with maize cultivation. Some important tangible and non-tangible benefits of maize replacing rice are mentioned below:

Parameters	Rice-wheat cropping system	Maize-based cropping system
Water requirement	Very high	Low (8-times lesser than rice)
Ground water pollution	Nitrate and pesticide leaching	No such problem
Planting/crop establishment	Cumbersome and labour consuming	Easier, only direct seeding
Per day productivity	Less	Higher
Soil physical health	Degrading crop	Restoring/improving crop
Cropping system optimization	Subsequent crop is affected, resulting in low system productivity and profitability	Subsequent crops are benefitted and results in higher system productivity and profitability.
Conservation agriculture	Very less scope	Highly suitable for conservation agriculture.
Silage	Not suitable	Best material for making silage which can be used in livestock and exported after meeting internal requirement.
Intercropping scope	Not suitable	Most suitable crop for growing pulses, vegetables and flowers due to wide spaced rows of the crop.

Source: Policy paper on Diversification of cropping system in Punjab and Haryana through cultivation of maize, pulses and oilseeds (2021), ICAR-IIMR, Ludhiana

Maize followed by wheat has higher system productivity than rice-wheat system due to scope for early sowing of wheat crop leading to escape of terminal drought. Further, there are immense scope of specialty corns (QPM, baby corn, sweet corn, pop corn) and can effectively be grown under chemical free/ organic system as sole or intercrop with other vegetables in peri-urban agriculture, giving avenue for additional income to the farmers.

Maize has predominantly industrial uses and scope of maize-based value chain is quite extensive, which principally may be dealt as feed, starch, ethanol, processed food, processed specialty corns (baby corn and popcorn) and silage.

While use of feed, starch and ethanol requires establishment of dedicated factories, processing of maize for food-like snacks and breakfast cereals or pet food requires smaller processing plants. Baby corn and popcorn processing also can be done in a micro level through aggregation of Farmers Producer Organizations (FPOs), Farmers Producer Companies (FPCs) and Self Help Groups (SHGs). There are enormous scope of establishment of such industries in these states and encourage contract farming benefitting both maize farmers and the industries, besides generating employments and addressing environmental and health issues.

Colour Plate 1



Fig. 1.5: Laser levelling for field preparation for DSR



Fig. 1.10: Seed spreading on polythene film by putting iron frame for raising mat type nursery



Fig. 1.6: Direct sowing of rice in laser levelled field



Fig. 1.11: Mat type nursery raising



Fig. 1.7: 50 days paddy crop raised under DSR



Fig. 1.12: Walk behind paddy planter



Fig. 1.8: Paddy crop in panicle stage under DSR



Fig. 1.13: Four-wheel paddy planter

Colour Plate 2



Fig. 2.3: Wheat variety HD 2967
(Courtesy: ICAR-IIWBR, Karnal)



Fig. 2.4: Wheat variety HD 3086
(Courtesy: ICAR-IIWBR, Karnal)



Fig. 2.5: Combine Harvester fitted with Super SMS in operation



Fig. 2.6: Sowing of wheat with Happy Seeder in standing stubbles of paddy



Fig. 3.4: Maize crop (Courtesy: ICAR-IIMR, Ludhiana)

Colour Plate 3

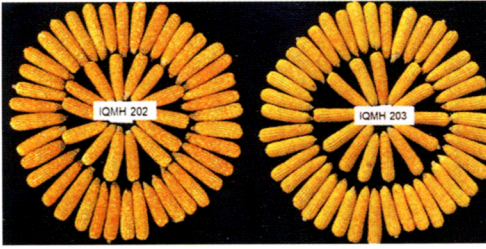


Fig. 3.5: Biofortified hybrids of maize: IQMH-202 & IQMH-203 (*Courtesy:* ICAR-IIMR, Ludhiana)



Fig. 3.6: Biofortified maize hybrid LQMH-1 (*Courtesy:* ICAR-IIMR, Ludhiana)

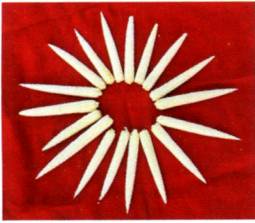


Fig. 3.7: IMHB-1539 hybrid of baby corn (*Courtesy:* ICAR-IIMR, Ludhiana)



Fig. 3.8: LBCH-3 hybrid of baby corn (*Courtesy:* ICAR-IIMR, Ludhiana)

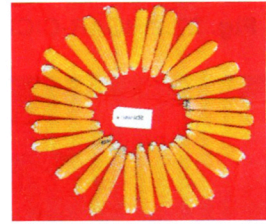


Fig. 3.9: LPCH-2 hybrid of popcorn (*Courtesy:* ICAR-IIMR, Ludhiana)



Fig. 19.2: Preparing of bed with machines for soybean (*Courtesy:* ICAR-IISR, Indore)



Fig. 19.3: Raised bed in soybean (*Courtesy:* ICAR-IISR, Indore)

Colour Plate 4



Fig. 27.2: ICAR-CICR Suraj Bt Cotton plant (*Courtesy:* ICAR-CICR, Nagpur)



Fig. 28.2: Jute variety JRO-204 in the farmers field (*Courtesy:* ICAR-CRIJAF, Barrackpore)



Fig. 37.2: Potato plants growing under aeroponic system (*Courtesy:* ICAR-CPRI, Jalandhar)



Fig. 37.3: Minitubers of 'Kufri Pukhraj' grown under aeroponic system (*Courtesy:* ICAR-CPRI, Jalandhar)



Fig. 37.4: Aeroponic potato seed production (*Courtesy:* ICAR-CPRI, Jalandhar)

Sorghum

(*Sorghum bicolor* (L.) Moench)

Sorghum is one of the four major foodgrains of the world. Millions of people in Africa and Asia depend on sorghum as the staple food. In addition, the fodder and stover is fed to millions of animals providing milk and meat for man. It is also used as industrial raw material in various industries in USA and other developed countries.

Sorghum (jowar) ranks third in the major foodgrain crops of our country. Besides being a major source of staple food for humans, it serves as an important source of cattle feed and fodder. It has potential to compete effectively with crops like maize under good environmental and management conditions. The greatest merit with sorghum is that it has capacity to withstand drought. Its performance is better than maize in marginal lands under moisture stress or excessive moisture conditions. It is one of the most widely grown dryland foodgrains in India. It does well even in low rainfall areas. It makes comparatively quick growth and gives not only good yields of grain but also very large quantities of fodder.

Sorghum grain is eaten by human beings in India either by breaking the grain and cooking it in the same way as rice or by grinding it into flour and preparing '*chapatis*'. To some extent it is also eaten as parched and popped grain. This grain is also fed to cattle, poultry and swine. Sorghum grain contains about 10–12% protein, 3% fat and 70% carbohydrate, therefore, it can satisfactorily replace other grains in the feeding programme for dairy cattle, poultry and swine.

ORIGIN AND HISTORY

Cultivated 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 of cultivated types decreases towards, Southern Africa, and Asia. Although several of the wild species have been collected in India, but there is no evidence of an independent origin of cultivated sorghum in India because the general types grown here are abundant in Africa.

The date of arrival of cultivated sorghum in India is uncertain. The movement of sorghum out of Africa to East was probably brought out through the dhow traffic. The trading route between East Africa and India, via Arabia, is ancient. Sir George Watt (1893) pointed out there was no specific Sanskrit name for sorghum. It is, therefore, supposed that sorghum reached India in 1500 BC.

AREA AND DISTRIBUTION

Sorghum is the fourth most importance crop among the world's leading cereals being cultivated over an area of about 40.1 million hectares with a production of about 57.9 million tones with a productivity of 1444 kg/ha in 2019 (FAOSTAT). Among the sorghum growing countries, India ranks third in acreage and seventh in production, however, USA, being the largest producer in the world. The other important sorghum growing countries are Sudan, Nigeria, India, Niger and United States of America.

In India, sorghum is grown in 4.82 million ha with production of about 4.77 million tones (2019-20) with an average yield of 989 kg/ha (<https://www.indiastatagri.com>). Maharashtra, Karnataka, Tamil Nadu, Uttar Pradesh and Andhra Pradesh are important sorghum growing states.

CLASSIFICATION

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 all these sorghums 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 thousands 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 the new scheme. The system partitions the variations in *Sorghum bicolor* (Linn) Moench into the following races:

Basic Races

1. *Bicolor*
2. *Guinea*
3. *Caudatum*
4. *Kafir*
5. *Durra*

Hybrid Races

1. *Guinea—bicolor*
2. *Caudatum—bicolor*
3. *Kafir—bicolor*
4. *Durra—bicolor*
5. *Guinea—caudatum*
6. *Guinea—kafir*
7. *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).

BOTANICAL DESCRIPTION

Sorghum, locally known as jowar, is an annual plant that belongs to *Poaceae* family (formerly called *Gramineae*) and genus *Sorghum*. Height of the plant varies from 0.5 to over 4 m. The botanical description of main parts of sorghum plant is given as follows:

Root System

Sorghum plant has a well-developed root system. Roots are generally thinner and more fibrous than maize. The only temporary root in sorghum is the single radicle of the germinating seedling, 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 cm of soil, but in later stages of development, they may reach a depth of 1 or 1.5 m. 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, though the centre may become spongy, with spaces in the pith. The thickness of the stem at base varies from 1 to 5 cm in diameter. The number of nodes differ 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. Certain introduced fodder varieties are more juicy and sweeter than common grain varieties.

Leaves

The number of leaves on the mainstem 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 is 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 cm, and a width of between 1.5 and 13 cm at the widest point. The stomata occur on both surfaces 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

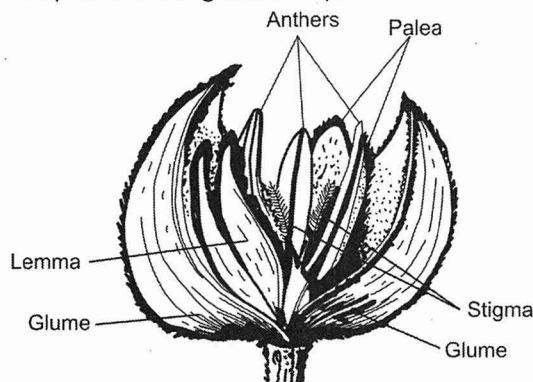


Fig. 4.1: Fertile spikelet of sorghum

length of the leaf sheath may vary between 15 and 35 cm. The sheath is smooth with a powdery bloom of wax on the upper side, and when tile deposit is heavy, the sheaths have a bluish-white appearance.

Inflorescence

The inflorescence of sorghum is a panicle. The panicles are commonly known as 'heads' and vary a great deal in size ranging from 7.5–50 cm in length and 4 to 20 cm 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 spikelets, which usually occurs 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 spikelets mature. In varieties where seed is produced in pedicelled spikelet, is always much smaller than those of the sessile spikelets. Sorghum is generally a self-fertilised crop. Sorghum flowers begin to open after the inflorescence has come out of the sheath. The first flowers 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. As the glumes spread, the stigma and anthers emerge. Pollens are produced in huge quantities from anthers which open as the filament,

start their rapid elongation. Since at this time the stigmas are receptive, self-pollination takes place.

Caryopsis (Grain)

The grains are rounded, 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 or 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 10 to 12%. It is poor in lysine content (1.4–2.8%) while very rich in leucine (7.4–17%).

CLIMATIC REQUIREMENTS

Sorghum requires warm climate but can be grown under a wide range of conditions. It is grown from sea level to as high as 1500 m. Sorghum plants can tolerate high temperatures throughout their life cycle better than any other cereal crop. It can tolerate drought conditions very well because it remains dormant during moisture stress conditions but resumes growth when favourable conditions reappear. It has a high resistance to desiccation, low transpiration ratio and a large number of fibrous roots. It can also tolerate water logging conditions better than any other cereal except rice. Therefore, sorghum can be grown successfully in areas having an average annual rainfall between 60 and 100 cm.

It is grown as a *Kharif* crop in northern India. In western and southern parts of the country it is grown also as a *Rabi* crop. The minimum temperature for the germination of sorghum seeds is 7–10°C. It needs about 26–30°C temperature for its optimum growth. Sorghum is a short day plant. Flowering is hastened by short days and delayed by long days. The time of heading in sorghum is influenced by temperature as well as photoperiod. Sorghum varieties vary in their sensitivity to both temperature and photoperiod.

SOILS

Sorghum is grown in a variety of soils in India. Soils with clay loam or loam texture, having good water retention capacity are best suited for sorghum cultivation. It does not thrive in sandy soils but does better on heavier soils. It does well in pH range of 6.0–8.5 as it tolerates considerable salinity and alkalinity. The black cotton soils of Central India are very good for its cultivation.

VARIETIES

A number of promising hybrid and composite varieties of sorghum have been evolved for grain and fodder purpose for commercial cultivation in different states. These are furnished in Tables 4.1 to 4.4.

Table 4.1: Recommended Kharif sorghum hybrids for cultivation in different states of India

Sl. No.	Hybrid	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Maturity (days)	Area for which recommended
1	CSH 21	2005	43	110	115	For the zones—I and II Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan, Uttar Pradesh
2	CSH 23	2005	41	87	105	For the zones—I and II Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan, Uttar Pradesh
3	CSH 25	2008	43	127	115	Kharif hybrid: Rainfed kharif sorghum areas under normal time of sowing especially for Maharashtra and Karnataka and central zone II areas
4	CSH 26	2011	43	142	109	Maharashtra, Karnataka, MP, south Gujarat, and north AP and TN
5	CSH 27	2011	39	136	104	Rajasthan, north Gujarat, UP, AP and Tamil Nadu
6	CSH 28	2012	47	152	111	Maharashtra, Karnataka, MP, south Gujarat, and north AP (Zone II)
7	CSH 29	2012	49	152	111	Maharashtra, Karnataka, MP, south Gujarat, and north AP (Zone II)
8	CSH 30	2012	43	140	103	Maharashtra, Karnataka, MP, south Gujarat, north AP under rainfed Kharif cultivation
9	CSH 32	2013	50	142	107	Maharashtra, Karnataka, MP, south Gujarat, and north AP
10	CSH 33 (NSH 55)	2014	45	118	96–100	Rajasthan, UP, North Gujarat, south Andhra Pradesh and TN
11	CSH 34	2014	45	129	113	Maharashtra, Karnataka, MP, AP, Chhattisgarh, Gujarat, and Rajasthan
12	CSH 35	2015	41	126	109	Maharashtra, Karnataka, MP, south Gujarat, and Telangana

Source: Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture, Govt. of India

Table 4.2: Recommended Kharif sorghum varieties for cultivation in different states of India

Sl. No.	Hybrid	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Maturity (days)	Area for which recommended
1	CSV 15	1996	36	121	232	Maharashtra, Karnataka, AP, MP, UP, Gujarat, Rajasthan, Tamil Nadu
2	CSV 17	2002	25	68	150	Low rainfall and drought prone sorghum growing regions of the country
3	CSV 20	2006	31	133	240	All sorghum areas of India
4	CSV 27	2012	28	193	116	All sorghum areas of India
5	CSV 28	2012	28	170	110	All sorghum areas of India
6	CSV 31	2014	33	144	110	Andhra Pradesh, Tamil Nadu, Rajasthan and Gujarat

Table 4.3: Details of nationally released rabi sorghum varieties

Sl. No.	Hybrid	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Maturity (days)	Area for which recommended
1	CSV 7R	1974	20	—	120	Maharashtra, Karnataka, Tamil Nadu, Gujarat, AP
2	CSV 8R	1979	22	48	215	Maharashtra, Karnataka, and AP
3	CSV 14R	1992	23	55	165	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Gujarat
4	CSV 216R	2000	21	59	220	AP, Gujarat, Karnataka, parts of MP, Maharashtra, and Tamil Nadu
5	CSV 18	2005	35	87	227	For zone II Maharashtra, Karnataka, AP under irrigation
6	CSV 22	2007	23	71	200	Maharashtra, Karnataka, Tamil Nadu, Gujarat, AP
7	CSV 26	2011	10	42	117	Rabi season. Under shallow soils conditions of rabi sorghum growing areas
8	CSV 29R	2012	25	67	118	of India Rabi sorghum growing areas of Maharashtra, Karnataka, and Andhra Pradesh under deep black soils
9	M35-1	1969	19	55	206	Maharashtra
10	Swati	1984	22	53	175	Maharashtra

Source: Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture, Govt. of India

Table 4.4: Improved sorghum fodder varieties suitable for growing in different states

State	Recommended varieties
Andhra Pradesh	Pusa Chari 1, Pusa Chari 9, Pusa Chari 23, UP Chari 1, UP Chari 2
Gujarat	MP Chari, Rajasthan Chari 1, Rajasthan Chari 2, NC 17, HC 136, HC 260
Haryana	JS 20, JS 263, HC 136, HC 171, HC 260, HC 308
Karnataka	Pusa Chari 1, Pusa Chari 9, Pusa Chari 23, UP Chari 1, UP Chari 2
Madhya Pradesh	Vidisha 60 1, MP Chari, Jawahar Chari 6, Jawahar Chari 69, Pusa Chari 23
Maharashtra	Pusa Chari 1, Pusa Chari 6, Pusa Chari 9, Pusa Chari 21, HC 136, HC 260, UP Chari 1
Rajasthan	Rajasthan Chari 1, Rajasthan Chari 2, SL 44, HC 17, UP Chari 1, UP Chari 2
Tamil Nadu	Pusa Chari 6, Pusa Chari 9, Pusa Chari 23
Uttar Pradesh	UP Chari 1, UP Chari 2, UP Chari 3, UP Chari 4, SL 44, MP Chari, HC 260, Pusa Chari 9, Pusa Chari 23

CROPPING SYSTEMS

Most of the high-yielding varieties and hybrids of sorghum mature in about 90–120 days, and they fit very well in multiple crop rotations and mixed cropping. Some of the cropping systems with sorghum are given as follows:

North India

1. Sorghum—wheat
2. Sorghum—wheat—cheena
3. Sorghum—wheat—moong
4. Sorghum—pea
5. Sorghum—gram
6. Sorghum—wheat—lobia
7. Sorghum—potato—wheat

South India

1. Sorghum—cotton
2. Sorghum—sorghum (*Rabi*)
3. Sorghum—tobacco
4. Groundnut—sorghum (*Rabi*)
5. Sorghum—ragi—groundnut
6. Sorghum—cotton—groundnut

Mixed cropping of sorghum + soybean, sorghum + pigeon pea, sorghum + moong and sorghum + blackgram have been found to be more profitable in north India. Sorghum hybrid CSH 35 has been found to be more suitable for mixed cropping. In south India, mixed cropping of sorghum + pigeon pea, sorghum + greengram, sorghum + blackgram have been found more profitable during *Kharif* season. In case of *Rabi* sorghum, sorghum + safflower and sorghum + sunflower are popular systems.

FIELD PREPARATION

Sorghum seed should be drilled in a well-prepared seedbed free from weeds. The first ploughing should be done with soil turning plough so that 20–25 cm deep soil may become loose. It should be followed by two to three harrowings or three to four intercrossing ploughings with country plough. Thereafter planking should be done to break the clods and to level the field. In black cotton soil area, if the land is badly infested with weeds, ploughing followed



Fig. 4.2: High-yielding sorghum hybrid (Courtesy: FAI)

by harrowings is usually practised, but where land is free from weeds or with few weeds, the land is cultivated only with bakhar (blade harrow).

SEED AND SOWING

The seed should be purchased from a reliable source. Always use certified seed. If seed is not already treated, treat it with Thiram @ 3 g/kg seed. In case of hybrids use new hybrid seed every year.

Seed Rate and Spacing

To ensure good stand 12–15 kg seed/ha is considered sufficient. There should be 150000 plants/ha to attain maximum yield. The seed should be sown in rows 45 cm apart. Plant to plant distance should be 12 cm. Seed should be sown at a depth of 3–4 cm. It should not be sown more than 5 cm deep in any case.

Method of Sowing

In northern India sorghum is sown either by broadcasting or in rows behind the plough. Seeds of new hybrids and varieties should always be sown in lines for obtaining higher yield. Sowing in rows is common in black cotton soil.

Time of Sowing

In India sorghum is grown in the following three seasons:

- | | |
|-----------|---------------------------|
| 1. Kharif | June–July |
| 2. Rabi | Mid-September–Mid-October |
| 3. Summer | Mid-January–Mid-February |

In northern India sorghum is sown only in *Kharif* season. In irrigated areas, first week of July has been found most suitable for sowing of most hybrids and improved varieties. Under unirrigated conditions, sowing should be done preferably within a week of the onset of first monsoon showers. Timely planted crop escapes the damage due to shoot fly and midge. Late planting may not fit well in multiple rotations.

Rabi sowing is done mainly in Maharashtra, Karnataka and Andhra Pradesh. *Rabi* sowing should be done from the second fortnight of September to the middle of October.

Summer crop of sorghum is sown in the month of January and February in irrigated areas of Tamil Nadu, Andhra Pradesh and some areas of Karnataka.

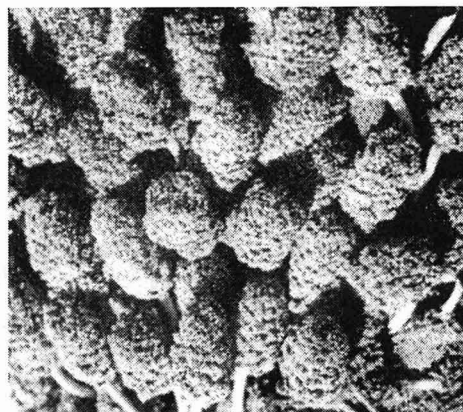


Fig. 4.3: Cobs of high yielding variety of sorghum (Courtesy: FAI)

MANURES AND FERTILISERS

Sorghum requires heavy doses of fertilisers because it removes nutrients in heavy amount from the soil. Manures and fertilisers both play important roles in the sorghum cultivation. In the rainfed areas, application of farm yard manure or compost @ 10 to 15 tonnes/ha improves the water holding capacity and microbial activities in the soil, besides providing essential nutrients to the crop. Farm yard manure or compost should be added in the field at the time of last ploughing.

The quantity of fertilisers to be applied varies according to the fertility status of the soil. However, when soil test data are not available, apply 100–120 kg nitrogen, 50 kg P_2O_5 and 40 kg K_2O /ha for hybrids and improved varieties of sorghum under irrigated condition. Half dose of nitrogen and total amount of phosphorus and potash should be applied at the time of sowing. The basal dressing can be done with the help of fertiliser-cum-seed drill. The fertiliser should be placed 3–5 cm to the side and 3–5 cm below the seed. If ferti-seed drill is not available fertiliser mixture may be spread uniformly in the field and mixed thoroughly in the soil with the help of a harrow or cultivator.

The remaining half quantity of nitrogen should be top dressed after 30–35 days of sowing. In light soils top dressing should be done in two splits. Half of the above dose should be applied in case of local varieties for better results. In case of rainfed crop, quantity of fertiliser should be reduced to half of the irrigated and the entire quantity should be applied 8 cm deep in soil at the time of sowing.

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

Nitrogen: Tips of lower leaves are first to show yellowing. If nitrogen deficiency persists the yellowing will follow-up the leaf midrib in typical

V-shaped pattern. After sometime the entire leaf turns yellow, it dies and dries up.

Phosphorus: Plants show stunted growth and leaf tip and leaf margins turn dark to light purple in colour.

Potash: The marginal discolouration along the edges of older leaves continues from tip to the base of the leaf. In severe cases the marginal discoloured area becomes dry and scorched. Eventually leaf edges and top dry leaving small areas at the bases and midrib alive and green.

Iron: Sorghum is most sensitive to iron deficiency. Iron chlorosis can be identified by intervenal chlorosis which extends to full length of leaves.

Zinc: Broad band of bleached tissue on each side of midrib. The midrib and leaf margin remains green. Stunted growth and short internodes. In zinc deficient soils, application of 20–25 kg/ha of zinc sulphate (20% Zn) at the time of sowing has been recommended.

THINNING

Thinning is a very important operation in sorghum cultivation for maintaining desired plant population. Ensure 12–15 cm plant to plant spacing in a row by thinning out extra plants at two stages. First, thinning should be done 10–15 days after emergence and second, when crop is 20–25 days old. All diseases and insect infested plants should be removed while thinning.

WATER MANAGEMENT

Usually, sorghum is grown as a rainfed crop. The irrigation should, however, be provided whenever, rains are not received. At the time of flowering and grain filling stages, the crop requires more water. If enough moisture is not there in the soil at the time of flowering and grain filling, it should be irrigated at once. At no stage, the plants should be allowed to wilt. Suitable drainage conditions should be provided for the removal of excess rain water from the field.

WEED CONTROL

During *Kharif* season both grassy and broad leaved weeds grow with sorghum crop. They cause severe crop-weed competition. In case the weeds are not brought under control at the right time, there is 20–60% reduction in yield. Sorghum crop is infested with *Echinochloa colonum*, *Echinochloa crusgalli* (sawan), *Dactyloctenium aegypticum* (makra), *Eleusine indica* (kodo), *Setaria glauca* (bandrabandri) *Cyperus rotundus* (motha), *Sorghum halepense* (banchari), *Cynodon dactylon* (doob) and *Phragmites karka* (narkul). Weeds should be removed with the help of *khurpi* or hand hoe when crop is about three weeks old. In case manual weeding is not possible use atrazine @ 0.5 to 1.0 kg active ingredient/ha. This herbicide should be used as pre-emergence.

The weedicide should be mixed in 800–1000 L 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 clods and any emerging weed. Field should not be disturbed for initial 3–4 weeks.

DISEASES

Sorghum crop suffers from a number of diseases resulting in considerable loss in yield. Symptoms of important diseases and their suitable control measures are given as follows:

Seed Decay and Seedling Blight

The seeds that may look apparently healthy usually harbour several fungi, either inside or on the surface. These fungi not only decrease germination but also cause different types of seedling blights. The fungi of seed or surrounding soil may attack shoot and root causing death of seedling. In some cases, seedlings are infected at the collar region and near the roots, turning these parts dark brown and thereby causing wilting and eventually death.

Control Measures

- Use quality seed and practice optimum water management practices, especially avoiding overwatering the first few weeks after planting.
- Crop rotation and destroying old corn stalks are helpful in controlling diseases.
- Seed treatment with Vitavax + Thiram @ 3 g/kg of seed.

Downy Mildew

This disease is caused by *Peronosclerospora sorghi*. On the young leaves downy whitish growth, mostly on the lower surface with yellowing on the corresponding upper surface is seen. Such leaves become shredded in due course. If the infection takes place during early stages of plant growth, the plants become severely stunted and ears do not form.

Control Measures

- Crop rotation with other crops like pulses and oilseeds.
- Avoid the secondary spread of the disease by rouging out the infected plants since the wind plays a major role in the secondary spread of the disease.
- Grow moderately resistant varieties.
- Metalaxyl-M 31.8% ES @ 2.0 ml/kg seed used as seed dresser or Metalaxyl 35% WS @ 0.75–1.0/100 kg seed used as slurry seed treatment.

Leaf Rust

This disease is caused by *Puccinia purpurea*. It is more common in southern parts of India than in the northern parts. The intensity of infection is high in warmer regions with higher relative humidity. Rust may appear at any stage but it is more severe after flag leaf stage. Infection starts on the lower leaves, especially towards margins and tips. Pustules are formed mainly on lower

surface. Reddish or purplish discoloration around the pustules are prominently seen. Due to production of rust spores, a light brown dust-like coating is seen on the infected leaves.

Control Measures

- Use short duration and resistant varieties.
- Remove the alternate host *Oxalis comiculata*.

Anthracnose

It is caused by *Colletotrichum graminicola*. It affects seedlings as well as matured plants. Small red purple or brown spots with whitish or purple centres occur on lower leaves. Later, black dot like fungal fruiting bodies (acervuli) appear in the centre of the spot.

Control Measures

- Grow resistance varieties and use healthy seed.
- Treat the seed with Thiram or Vitavax @ 2.5 g/kg of seed.
- Spray 0.2% Zineb or Mancozeb 75 WP or Propiconazole (Tilt) 0.1% at 10–15 days interval.

Leaf Blight

It is caused by *Helminthosporium turcicum*. The pathogen is known to cause seed rot and seedling blight of sorghum. On the young leaves, lesions are small, narrow and water-soaked. Later on these become elongated along with the length of the leaf and turn into straw colour or brown with the dark margins. The colours of the lesions are yellow, red or black, depending on the cultivar.

Control Measures

Same as described for Anthracnose disease.

Zonate Leaf Spot

This disease is caused by *Gleocercospora sorghi*. The disease is quite severe in northern and central parts of the country. The spots first appear as small red to brown water-soaked lesions. Later such spots become dark coloured and form large zonate semi-circular or irregular lesions extending across the leaf blade.

Control Measures

- Due to cost, fungicide applications for the management of Zonate Leaf Spot are not feasible in grain production. Residue management by crop rotation is the most feasible disease management option:

Grey or Cercospora Leaf Spot

It is caused by *Cercospora sorghi*. Severe infection of the disease leads to drying of the leaves. The spots are seen on both surfaces of leaves as isolated rectangular lesions which are mostly confined between veins. The spots may be red, purple, brown or straw coloured.

Control Measures

- Spraying with Zineb @ 0.2% has given satisfactory control of this disease. Three sprays after 30, 45 and 60 days of planting may be sufficient.
- Grow resistant varieties and use healthy seeds.

Grain Smut

This disease is caused by *Sphacelotheca sorghi*. The disease is quite destructive but can be controlled easily. Symptoms become visible at the time of grain formation in the ear. Smut sori are formed in place of healthy grains and are scattered on the ears. They are generally larger than the normal grains.

Control Measures

- Use disease-free seeds.
- Practice crop rotation.
- Collect the smutted ear heads in cloth bags and bury in soil.
- Use Sulphur 80% WP @ 3–4 g/kg seed for seed treatment.

Loose Smut

It is caused by *Sphacelotheca criuenta*. The affected plants are stunted, produce thinner stalks, more tillers and flower earlier than the healthy plants. All spikelets of an infected ear are malformed and hypertrophied. The affected ear appears like a mass of leafy or leathery structures.

Control Measures

Control measures of this disease are same as for grain smut.

Ear Moulds

Several fungi can grow on developing ears of sorghum when the grain setting coincides with rains or excessive humidity. The infection is more severe on grains if damaged by head bug. The infected seeds lose their market value and show poor germination. To control the disease grow early maturing varieties.

Ergot or Sugary Disease

The disease is caused by *Sphacelia sorghi* and confined to individual spikelets. The first symptom is the secretion of honey dew from infected florets. Under favourable conditions, long, straight or curved, cream to light brown, hard sclerotia develop. A period of high rainfall and high humidity during flowering season and cool night temperature and cloudy weather aggravate favourable for the disease development.

Control Measures

- Adjust the date of sowing so that the crop does not flower during September–October when high rainfall and high humidity favour the disease.

INSECT PESTS

Sorghum crop is subject to attack by a number of insect pests. A brief description of the major ones, their nature of damage and appropriate control measures are as follows.

Sorghum Shoot Fly

It is a major pest of sorghum, attacking in the early seedling stage of plant growth. Plants up to three-week age are more susceptible to this pest. The fly lays oval white eggs on the lower surface of the leaves, stem or on the soil near the base of plants. Within two days or so, the eggs hatch and the tiny maggots creep down under the leaf-sheaths and cut the central growing point of the plant which results in the 'dead heart'. The pest is so serious that sometime re-sowing may be required.

Control Measures

Spray cypermethrin 10 EC @ 550 ml or diflubenzuron 25 WP @ 1155 g or imidacloprid 48 FS @ 1200 ml by using 800 litres of water per hectare

Stem Borer

This pest attacks sorghum crop throughout the growing season. In an early stage of the crop, larvae bore inside the tender stem and feed on the tissues resulting into the death of growing point which is commonly known as 'dead heart'. Grown up plants are not killed but suffer in vigour, develop weak heads. It causes damage up to 80%. The caterpillars that feed on tender parts of the plant are cylindrical and yellowish brown, when fully grown are about 2.5 cm long.

Control Measures

Adopt the following integrated control measures:

- Use higher seed rate and pull all affected plants in an early stage of the crop
- Remove and destroy the plants showing severe borer injury, while hoeing the crop.
- Kill the borer larvae hibernating in plant remnants like stubbles, stalks, and cores.
- Spray the crop 2–3 weeks after sowing as soon as borer injury to the leaves is noticed with 150 ml chlorantraniliprole 18.5 SC (Coragen) using 300 litres water.

Pink Borer

The adult is stout, straw-coloured with faint forewings. Fully grown caterpillar is 2.5 cm in length and pink in colour on dorsum while its ventrum is white. Caterpillars bore into the stem or shoot. The 'dead heart' is formed in early stage of the crop.

Control Measures

Spray 2 litres Ekalux 25 EC (quinalphos) in 1000 litres of water per hectare with hand operated knapsack sprayer. It can also be controlled by spraying with 100 ml chlorantraniliprole 18.5 SC (Coragen) in 300 litres of water.

Sorghum Midge

It is one of the most widely distributed and important pests of sorghum. The fly lays its eggs in the flowers and the larvae develop on their ovary which shrivel and fail to bear grains. The larvae pupate in the spikelets. Due to its infestation grain fails to develop and in cases of severe attack the whole head may be damaged resulting in a significant loss in the production of sorghum.

Control Measures

- Plant pure and uniform seeds so that all plants come in flowering at the same time
- Destroy the crop debris in the field by burning
- Apply chlorpyrifos or quinalphos dust @ 25 kg/ha or spray the crop with Ekalux 25 EC (quinalphos) @ 2.0 litre in 1000 litres water.

Leaf Roller

The caterpillar is a slender yellowish green worm but is pinkish when fully fed. Eggs are laid by the female moth on the tip of the leaf. Caterpillar after hatching moves about and folds or rolls up the leaf by bringing the two margins closely with the help of silken thread and hides and feeds inside this roll. Due to this the feeding leaf becomes white papery in appearance.

Control Measures

Spray the crop with buprofezin 25 SC @ 800 ml or bifenthrin 10 EC @ 500 ml in 250–300 litres of water.

Sorghum Ear Head Bug

Both adults as well as nymphs suck the milky juice of the developing grains due to which the grains remain chaffy or shrivelled. When a large number of nymphs feed, the whole earhead may become blackened at first and may eventually dry up, producing no grains.

Control Measures

- Remove all the plants of wild sorghum in the surroundings
- It can be effectively controlled by spraying flubendiamide 39.35 SC (Fame) @ 100 ml or thiodicarb 75 WP (Larvin) @ 750 ml using 300 litres water.

Hairy Caterpillar

There are about seven species of hairy caterpillars which feed on sorghum. They are all polyphagous and feed on different crops and wild weeds. They are called hairy caterpillar because they have profuse hairy growth on their

body. The adults emerge after good monsoon showers and the females after mating lay eggs in clusters on the leaves of wild as well as cultivated plants. These eggs hatch within three to four days. The tiny larvae feed gregariously on the same plant for some days and then migrate to other plants and feed on leaves leaving only their veins.

Control Measures

- Collect the egg masses and destroy them
- The light traps should be used as soon as moths are visible after rain starts
- Spray cypermethrin 10EC @ 650 ml or indoxacarb 15.8 EC @ 333 ml or 100 ml chlorantraniliprole 18.5 SC (Coragen) using 300 litres water.

HARVESTING AND THRESHING

Most of the high-yielding sorghum hybrids and varieties take about 100–115 days to mature. The crop should be harvested immediately after it is mature. The right stage for harvest is when grains have become hard having less than 25% moisture. Do not wait for stalks and leaves to dry because plants of hybrid sorghum appear green even after the crop is mature. Harvesting is done by cutting the entire plant or removing the earheads first and cutting down the plants later on. In the areas where there is danger of rain at the time of harvesting, the mature earheads should be harvested first and plants cut and heaped later on.

Threshing is done with the help of threshers or by beating the earheads with sticks or by trampling bullocks. The threshed grain should be cleaned and dried in sun for about a week to bring the moisture content down to 13–15% for safe storage.

YIELD

With improved cultural practices it is possible to harvest nearly 50 quintals of grain and about 100–125 quintals of dry stover from a hectare of crop under irrigated conditions and about 25–30 quintals of grain and about 80–100 quintals of dry stover from a rainfed crop.

Pearl Millet (Bajra)

(*Pennisetum typhoides* L.)

Pearl millet (bajra) is one of the major coarse grain crops and is considered to be a poor man's food. It is widely grown in Africa and Asia since prehistoric times. It is grown in Africa where it replaces sorghum as the principal crop on sandy soils and in the drier areas. In Asia it is an important cereal crop of India, Pakistan, China and south eastern Asia. In India it is one of the important millet crops which flourishes well even under adverse conditions of weather. 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 among cereals and millets.

The grain of pearl millet is superior in nutritive value to sorghum grain but inferior in feeding value. Bajra grains contain about 12.4% moisture, 11.6% protein, 5% fat, 67% carbohydrates and about 2.7% minerals. Pearl millet (bajara) grains are eaten cooked like rice or '*chapatis*' are prepared out of flour like maize or sorghum flour.

It is also used as feed for poultry and green fodder or dry hay for cattle.

ORIGIN AND HISTORY

Most of the scientists believe that the primary centre of origin of pearl millet is Africa from where it spreads to India and other countries. Pearl millet (*Pennisetum typhoides*) hybridises spontaneously with Elephant grass (*Pennisetum purpureum*) which is of African origin, and the two species may have had a common ancestor. Out of 32 species described by Staph (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 greatest range of variability was found in the strains from Africa. This is a further evidence of the African origin of Pearl millet.

AREA AND DISTRIBUTION

Pearl millet is a crop grown mostly in tropical climate. It is widely grown in Africa and Asia. The important Pearl millet growing countries are India, China, Nigeria, Pakistan, Sudan, Egypt, Arabia and Russia.

In India, Pearl millet is grown in an area of about 7.54 million hectares with production of 10.36 million tones during 2019-20 with an average productivity of 1374 kg/ha (<https://www.indiastatagri.com>). Rajasthan, Uttar Pradesh,

Maharashtra, Haryana, Gujarat and Karnataka are important pearl millet growing states. Rajasthan (45 percent), Uttar Pradesh (19 percent) and Haryana (10 percent) are leading producers of Pearl millet and accounts for third fourth production of the country. The production of Pearl millet fluctuates with the vagaries of monsoon and incidence of pest and diseases.

CLASSIFICATION

No good classification of pearl millet (bajra) has been worked out by any scientist in spite of the fact that there is a wide range of variability in the cultivated strains. Staph (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 others by the conspicuous Pennicillate anthers. Thirty-two species belong to section *Pennicillate*.

BOTANICAL DESCRIPTION

Pearl millet (*Pennisetum typhoides*) belongs to *Poaceae* (formerly called *Gramineae*) family. It is tall, tillering annual plant which usually grows to a height of one metre to over three metres. The botanical description of main parts of bajra plant is given as follows.

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 stage, the secondary roots develop from the bud located on lowermost 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 slightly swollen, while internodes are cylindrical and glabrous. The stem is about 2.5 cm in thickness. The length of the internode increases from the base 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 axillary 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 and 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 surfaces.

Inflorescence

The inflorescence of Pearl millet is almost a cylindrical spike densely packed with the spikelets. The number of spikelets may vary from 800 to 3000/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.

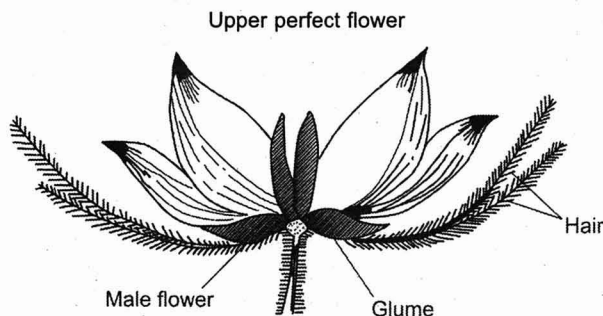


Fig. 5.1: Spikelet of Pearl millet

Two to three days after the emergence of the inflorescence, the bluish-white styles begin to protrude out of the glumes. They remain receptive for one to two days. The anthers begin to emerge after the styles have started to dry up. By the time the anther emergence starts, the whole panicle will show all the styles and stigmas emerged. Due to protogynous nature of the inflorescence usually cross pollination takes place.

Caryopsis (Grain)

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.

CLIMATIC REQUIREMENTS

Pearl millet is a rapid-growing warm weather crop suitable for areas with 40–75 cm of annual rainfall. It has a 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 the 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 grown in those areas where it is not possible to grow 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 pearl millet (bajra) is between 20 and 28°C.

SOIL

Pearl millet can be grown on a wide variety of soils, but being sensitive to water-logging, it does best on well-drained sandy loams. Pearl millet is sensitive to acidic soils. It is grown successfully on black cotton soils, alluvial soils and red soils of India.

VARIETIES

Several high-yielding hybrids and composite varieties of Pearl millet have been evolved for commercial cultivation in different states. These are furnished in Tables 5.1 to 5.4.

CROPPING SYSTEMS

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

1. Pearl millet—barley
2. Pearl millet—wheat
3. Pearl millet—chickpea
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, sesamum, urad 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 Hissar

Table 5.1: Improved varieties and hybrids of Pearl millet (bajra) for cultivation in different states of India

State	Improved varieties	Hybrids
Andhra Pradesh	Dhanshakti, Ananth, ICVM 221	Pratap, Shine, 86 M01, 86 M88, NBH 5767, NBH 5061
Gujarat	Pusa Composite 701, Mandor Bajra Composite 2, Dhanshakti, Pusa Composite 443	Bio 8145, 86M82, KBH 3940, MH 1928, JK BH 1008, HHB 272, MPMH 21, Kaveri, KBH 108, GHB 905
Haryana	Pusa Composite 701, Dhanshakti, Mandor Bajra Composite 2, Pusa Composite 443	Bio 8145, 86M82, KBH 3940, MH 1928, JK BH 1008, NHB 272, MPMH 21, 86M84, 86M01, KBH 108, GHB 905, 86M89
Karnataka	Dhanshakti, Pusa Composite 612	Pratap, Kaveri, 86 M01, 86 M88, NBH 5767, NBH 5061, Shine, PAC 909, 86 M86
Maharashtra	Dhanshakti, Pusa Composite 612 ABPC-4-3, Parbhani Sampada, RHRBH 9808	Phule Adishakti, Nandi 72, Kaveri, Super Boss, Pratap, 86 M13, 86M01, 86M88, NBH 5767, NBH 5061
Madhya Pradesh	Dhanshakti, JBV 4	Bio 448, MH 1928, 86M82, 86M84, 86M01, KBH 108, GHB 905, MPMH 17, MP 7872, MP 7792
Punjab	PCB 164, FBC 16	Bio 8145, 86M82, KBH 3940, MH 1928, PHB 2884, KBH 108, GHB 905, MPMH 17
Rajasthan	Pusa Composite 701, Pusa Composite 443, Dhanshakti	Bio 8145, Nandi 75, 86M82, 86M13, KBH 3940, MH 1928, JKBH 1008, HHB 272, MPMH 21, KBH 108, Proagro Tejas, Kaveri Super Boss
Tamil Nadu	Dhanshakti, Pusa Composite 612, COCU 9	Shine, Nandi 75, Co 10, Pratap, 86M01, 86M88, NBH 5767, NBH 5061, 86M86, Co 9, PAC 909
Uttar Pradesh	Dhanshakti, Pusa Composite 383, Raj 171, JBV 2, Pusa Composite 334	Bio 8145, Nandi 75, Kaveri Super Boss, JKBH 1100, JKBH 1105, 86M82, 86M13, KBH 3940, MH 1928, KBH 108, GHB 905

(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.

FIELD PREPARATION

Pearl millet requires a fine seedbed free from clods as the seeds are of very small size. A deep ploughing (at least 15 cm deep) with soil-inverting plough followed by two or three harrowings is considered to be optimum. While levelling the field, care should be taken to ensure that rain water does not stagnate but drain out easily. If available, apply farm yard manure about a fortnight before starting to prepare the land. Adequate moisture in the seedbed at the time of sowing is conducive to good germination.

Table 5.2: Distinguishing characters of important varieties of Pearl millet

Variety	Year of release	Bred at	Area of adaptation	Maturity group and salient features
Pusa Composite 701 (MP 535)	2016	ICAR-IARI, New Delhi	Rajasthan, Haryana, Western Gujarat	Dual purpose variety, resistant to downy mildew and blast
Dhanshakti (ICTP 8203 and Fe 10-2)	2014	ICRISAT, Hyderabad	Maharashtra, Karnataka, AP, TN, Gujarat, MP, Rajasthan, UP, Haryana, Punjab	Variety with high iron (76–91 ppm) zinc (39–48 ppm), bold, globular, shining slate grey coloured seeds, cylindrical lanceolate, earheads, resistant to downy mildew and blast diseases
ABPC-4-3 (MP 484)	2012	AICPMIP, Aurangabad	Maharashtra	Late maturing, medium plant height, lanceolate earheads, globular grey seeds
Mandor Bajra Composite 2 (MBC 2) (MP 489)	2011	SKRAU, ARS, Mandor, Jodhpur	Rajasthan, Haryana, Gujarat	Early maturing, medium height medium long semi-compact cylindrical earheads, oblate grey coloured seed
Pusa Composite 612 (MP 480)	2011	AICPMIP IARI, New Delhi	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	Medium maturity, medium to tall plant height, compact cylindrical earheads
Pusa Composite 443 (MP 443)	2009	AICPMIP IARI, New Delhi	Rajasthan, Haryana, Gujarat	Early maturing, medium tall, rod-shaped earheads with bold grain
PCB 164	2007	AICPMIP PAU, Ludhiana	Punjab	85–88 days, dual purpose variety with bold leaves, thick stalks cylindrical earheads, bred from seven elite population and 27 diverse inbred lines
JBV 4 (MP 403)	2007	AICPMIP COA, Gwalior	MP	Mature in 75 days, medium tall, thick stemmed. Plants with many leaves, slate grey seeds
PPC-6 (Parbhani Sampada)	2005	AICPMIP RRS NARP, Aurangabad	Maharashtra	75–80 days, medium tall, light pink nodes, bold grains, bred from 8 inbred lines

Table 5.3: Distinguishing characters of important hybrids of Pearl millet

Variety/hybrid	Year of release	Bred at	Area of adaptation	Maturity group and salient features
Phule Aadishakti (DHBH 9071)	2016	MPKV, Dhule	Maharashtra	Late, grey globular seeds, resistant to downy mildew
KBH 1100 (MH 1810)	2016	JK Agri Genetics Ltd, Hyderabad	UP	Late, resistant to downy mildew, rust, smut diseases
KBH 1105 (MSH 254)	2016	JK Agri Genetics Ltd, Hyderabad	Summer areas of UP	Late, globular, grey brown grains, resistant to downy mildew, rust, smut diseases
Bio 8145 (MH 1970)	2016	Bioseed Research India Pvt. Ltd., Hyderabad	Rajasthan, UP, Punjab, Haryana, Gujarat, MP, Delhi	Late, grey coloured globular grains, resistant to downy mildew, rust, blast, ergot
86M82 (MH 1888)	2016	Pioneer Overseas Corp., Hyderabad	Rajasthan, UP, Punjab, Haryana, Gujarat, MP, Delhi	Late, grey coloured obovate seeds, resistant to downy mildew, rust, blast, ergot
86M13 (MSH 276)	2016	Pioneer Overseas Corp., Hyderabad	Rajasthan, Gujarat, UP, Maharashtra, TN	Late, grey coloured obovate seeds, resistant to downy mildew, rust, blast, ergot
Nandi 75 (MSH 287)	2016	Nandi Seeds Pvt. Ltd., Ahmedabad	Rajasthan, Gujarat, UP, Maharashtra, TN	Late, grey coloured globular grains, resistant to downy mildew, rust
KBH 3940 (MH 1984)	2016	Kaveri Seed Co. Ltd., Secunderabad	Rajasthan, UP, Punjab, Haryana, Gujarat, MP, Delhi	Late, grey coloured obovate seeds, resistant to downy mildew, rust, blast, ergot
MH 1928 (XMT 1497)	2016	Bayer Bio Science Pvt. Ltd., Hyderabad	Rajasthan, UP, Punjab, Haryana, Gujarat, MP, Delhi	Medium, grey-coloured hexagonal grains, resistant to downy mildew, rust, smut diseases
KBH 1008 (MH 1828)	2016	JK Agri Genetics Ltd, Hyderabad	Rajasthan, Gujarat, Haryana	Early, grey-coloured globular grains, resistant to downy mildew, blast

(Contd.)

Variety/hybrid	Year of release	Bred at	Area of adaptation	Maturity group and salient features
Co 10	2016	AICPMIP, TNAU, Coimbatore	Tamil Nadu	Medium, grey-brown bold grains, resistant to downy mildew
HHB 272 (MH 1837)	2016	AICPMIP, CCSHAU, Hisar	Rajasthan, Gujarat, Haryana	Early, grey-globular grains, resistant to blast
MPMH 21 (MH 1777)	2016	AICPMIP, Jodhpur	Rajasthan, Gujarat, Haryana	Early, grey-brown hexagonal grains, resistant to downy mildew, blast, smut
86M84 (MH 1890)	2016	Pioneer Overseas Corp., Hyderabad	Rajasthan, UP, Punjab, Haryana, Gujarat, MP, Delhi	Medium, tall plant with lodging tolerance, long compact ear head, high grain and fodder yield
86M01 272 (MH 1760)	2016	Pioneer Overseas Corp., Hyderabad	Maharashtra, Karnataka, AP, TN, Rajasthan, UP, Punjab, Haryana, Gujarat, MP, Delhi	82 days, purple anther colour, medium plant height, conical earheads, obovate grey-coloured grains
PHB 2884	2016	AICPMIP, PAU, Jodhpur	Punjab	Late, grey seeds
Proagro Tejas	2016	ProAgro, Hyderabad	Rajasthan	Early, resistant to downy mildew
86M88 (MH 1816)	2015	Pioneer Overseas Corp., Hyderabad	Maharashtra, Karnataka, AP, TN	86 days, a rainy hybrid with wider adaptability and excellent potential; it has high tolerance to leaf blast and rust
NBH 5767	2015	Nuziveedu Seeds Pvt. Ltd.	Maharashtra, Karnataka, AP, TN	83 days, purple anther, medium plant height, compact lanceolate earheads, deep grey-coloured grains
NBH 5061 (MH 1812)	2015	Nuziveedu Seeds Pvt. Ltd.	Maharashtra, Karnataka, AP, TN	89 days, purple anther, medium plant height, compact lanceolate earheads, grey-coloured grains
KBH 108 (MH 1737)	2014	Krishna Seed (P) Ltd., Agra	Rajasthan, Gujarat, Haryana, Delhi, UP, and MP	Late maturing tall plant height, purple anther colour, cylindrical very compact earheads, obovate grey seed, resistant to downy mildew, blast and smut

(Contd.)

<i>Variety/hybrid</i>	<i>Year of release</i>	<i>Bred at</i>	<i>Area of adaptation</i>	<i>Maturity group and salient features</i>
CHB 905 (MH 1655)	2013	AICPMIP, MRS, Jamnagar	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Medium maturing, medium height, yellow anther colour, compact cylindrical earheads with bristles, resistant to downy mildew, globular grey brown seeds
Nandi 72 (MSH 238) (NMH 75)	2013	New Nandi Seeds Corporation, Ahmedabad	Summer growing areas of Gujarat, Maharashtra, Rajasthan, and Tamil Nadu	Medium tall plant height, purple-coloured anthers, lanceolate thick compact earheads, resistant to downy mildew, globular deep grey seed
86M89 (MH 1747)	2013	Pioneer Overseas Corp., Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Late maturing, tall height, conical very compact earheads, yellow anther colour, resistant to downy mildew, obovate deep grey-coloured seed
MPMH 17 (MH 1663)	2013	AICPMIP, Jodhpur	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Medium maturing, medium height, yellow anther colour, compact lanceolate earheads with bristles, resistant to downy mildew, grey brown seeds
HHB 234 (MH 1561)	2013	AICPMIP, CCSHAU, Hisar	Western Rajasthan, and drier part of Gujarat and Haryana	Early maturing, candle-shaped earheads with small bristles, medium seed size and tolerant to downy mildew
Kaveri Super Boss (MH 1553)	2012	Kaveri Seed Co. Ltd., Secunderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, MP, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	Late maturing, tall height, long compact cylindrical earheads, purple anther colour, globular grey-coloured seed

(Contd.)

Variety/hybrid	Year of release	Bred at	Area of adaptation	Maturity group and salient features
Bio 70 (MH 1632)	2012	Bioseed Research India Pvt. Ltd., Hyderabad	Western Rajasthan, and drier part of Gujarat and Haryana	Early maturing, conical compact earheads, yellow anther colour, globular grey seed and tolerant to downy mildew
Bio 448 (MH 1671)	2012	Bioseed Research India Pvt. Ltd., Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Late maturing, cylindrical compact earheads, yellow anther colour, globular grey seed and tolerant to downy mildew
Nandi 70 (MSH 224)	2012	New Nandi Seeds Corporation, Ahmedabad	Summer growing areas of Gujarat, Maharashtra, Rajasthan, and Tamil Nadu	Medium plant height, cylindrical thick compact earheads, globular deep grey seed
Pratap (MH 1642)	2012	Nuziveedu Seeds Pvt. Ltd., Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	Medium maturity, medium plant height, cylindrical semi-compact earheads, globular grey seed
PKV Raj (BBH 3)	2012	Dr. PDKV, ARS, Buldana	Maharashtra	Medium maturing, medium height, conical compact bristled earheads, grey-coloured seed
MP 7872 (MH 1610)	2012	Metahelix Life Science Ltd., Bangalore	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Late maturing, medium height, yellow anther colour, spindle earheads, grey-coloured globular seed
MP 7792 (MH 1609)	2012	Metahelix Life Science Ltd., Bangalore	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Late maturing, medium height, yellow anther colour, cylindrical earheads, grey-coloured globular seed
86M86 (MH 1684)	2012	Pioneer Overseas Corp., Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, MP, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	Late maturing, medium to tall plant height, conical very compact earheads, purple anther colour, grey hexagonal seeds

Contd.)

<i>Variety/hybrid</i>	<i>Year of release</i>	<i>Bred at</i>	<i>Area of adaptation</i>	<i>Maturity group and salient features</i>
Co 9	2012	AICPMIP, TNAU, Coimbatore	Tamil Nadu	Medium maturing, medium height, candle compact earheads, greyish yellow seed colour
Shine (VBBH 3040) (MH 1578)	2012	Vibha Agrotech Ltd., Hyderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	Medium maturing, medium height, red node pigmentation, yellow anther colour, compact spindle-shaped earheads, resistant to downy mildew, grey bold seeds
86M66 (MH 1617)	2011	Pioneer Overseas Corp., Hyderabad	Rajasthan, Gujarat, Haryana, Punjab, Delhi, UP, and MP	Late maturing, medium height, conical compact earheads, brownish yellow anthers, broad leaves, purple node colour, grey seed colour, resistant to downy mildew
PAC 909 (MH 1435)	2011	Advanta India Ltd., Secunderabad	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu	Medium maturing, medium height, medium thick compact cylindrical earheads, light yellow-coloured anthers, grey seed colour, resistant to downy mildew
HHB 226 (MH 1479)	2011	AICPMIP, CCSHAU, Hisar	Western Rajasthan, and drier part of Gujarat and Haryana	Medium maturing, medium height, dark green leaves, candle-shaped bristled earheads, resistant to downy mildew

Source: Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture, Govt. of India

Table 5.4: Biofortified varieties/hybrids of pearl millet

Name	Variety	Biofortified attributes	Grain yield, dry fodder yield (Q/ha)	Maturity (days)	Adaptation	Developed
HHB 299	Hybrid	Rich in iron (73.0 ppm) and zinc (41.0 ppm) in comparison to 45.0–50.0 ppm iron and 30.0–35.0 ppm zinc in popular varieties/hybrids	32.7, 73.0	81	<i>Khurif</i> season in Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu	CCS-Haryana Agricultural University, Hisar
AHB 1200Fe	Hybrid	Rich in iron (73.0 ppm) in comparison to 45.0–50.0 ppm in popular varieties/hybrids	32.0, 70.0	78	<i>Khurif</i> season in Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
AHB 1269Fe	Hybrid	Rich in iron (91.0 ppm) and zinc (43.0 ppm) in comparison to 45.0–50.0 ppm iron and 30.0–35.0 ppm zinc in popular varieties/hybrids	31.7, 74.0	82	<i>Khurif</i> season in Haryana, Rajasthan, Gujarat, Punjab, Delhi, Maharashtra and Tamil Nadu	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
ABV 04	Open pollinated	Rich in iron (70.0 ppm) and zinc (41.0 ppm) in comparison to 45.0–50.0 ppm iron and 30.0–35.0 ppm zinc in popular varieties/hybrids	28.6, 58.0	86	<i>Khurif</i> season in Maharashtra, Karnataka, Andhra Pradesh, Telangana and Tamil Nadu	ARS, Acharya NG Ranga Agricultural University, Ananthapuram
Phule Mahashakti	Hybrid	Rich in iron (87.0 ppm) and zinc (63.0 ppm) in comparison to 45.0–50.0 ppm iron and 30.0–35.0 ppm zinc in popular varieties/hybrids	29.3, 56.0	88	<i>Khurif</i> season in Maharashtra	Mahatma Phule Krishi Vidyapeeth, Dhule

(Contd.)

Name	Variety	Biofortified attributes	Grain yield, dry fodder yield (Q/ha)	Maturity (days)	Adaptation	Developed
RHB 233	Hybrid	Rich in iron (83.0 ppm) and zinc (46.0 ppm) in comparison to 45.0–50.0 ppm iron and 30.0–35.0 ppm zinc in popular varieties/hybrids	31.6, 74.0	80	<i>Kharif</i> season in Rajasthan, Gujarat, Haryana, Madhya Pradesh, Delhi, Maharashtra and Tamil Nadu	Sri Karan Narendra Agricultural University, Jobner
RHB 234	Hybrid	Rich in iron (84.0 ppm) and zinc (46.0 ppm) in comparison to 45.0–50.0 ppm iron and 30.0–35.0 ppm zinc in popular varieties/hybrids	31.7, 70.0	81	<i>Kharif</i> season in Rajasthan, Gujarat, Haryana, Madhya Pradesh, Delhi, Maharashtra and Tamil Nadu	Sri Karan Narendra Agricultural University, Jobner
HHB 311	Hybrid	Rich in iron (83.0 ppm) in comparison to 45.0–50.0 ppm in popular varieties/hybrids	31.7, 72.0	81	<i>Kharif</i> season in Rajasthan, Gujarat, Haryana, Punjab, Delhi, Maharashtra and Tamil Nadu	CCS Haryana Agricultural University, Hisar

SEED AND SOWING

Use certified seed for sowing. For getting higher yields it is necessary to use new hybrid seed every year. Before sowing, seed lot must be tested for its germination percentage.

Seed Rate, Spacing and Method of Sowing

Four-five kg seed/ha is sufficient to ensure good stand. Plant density of 175,000–200,000 plants/ha is optimum. This could be attained by spacing rows 45 cm apart and plants 10–12 cm apart. Seeds should be sown about 2 to 3 cm deep. Bajra is generally sown behind plough or by broadcast method. These methods are quite unsatisfactory and generally lead to poor germination and consequently poor yield. Sowing bajra with bajra seed drill is the best method. It not only ensures best germination but uniform plant population as well.

Sowing Time

It is chiefly a rainfed crop grown during monsoon season. Sowing time in most of the states is June–July. However, it can be raised round the year in areas of assured water supply in south. In northern India, bajra is grown mainly in *Kharif* season. As a *Kharif* crop, optimum time of sowing is first fortnight of July. In case sowing is delayed there is a drastic reduction in yield due to more incidence of diseases like downy mildew and ergot, restricted vegetative growth of the crop, high rate of mortality and poor grain setting.

Transplanting of Seedlings

Timely sowing of Pearl millet may not be done due to several unavoidable reasons such as late onset of monsoon, heavy and continuous rain during the optimum sowing time or late harvesting of preceding summer crop. In case sowing is delayed, transplanting has been found to give higher yields as compared to direct sowing. It has the following distinct advantages:

1. Transplanted crop matures earlier and the low temperature late in the season has no adverse effect on grain setting.
2. It also produces more tillers and ears owing to better growth.
3. Optimum plant population is ensured.
4. Transplanted crop gets a better start because the three week old seedlings are able to withstand frequent rains.
5. Downy mildew infected seedlings are rejected at the time of transplanting itself.

About 2 kg seed of Pearl millet is sown in 500–600 sq m area in nursery to get seedlings for 1 ha. The seeds are sown in flat beds (1.20 × 7.50 m) in rows 10 cm apart and at 1.5 cm depth. To give better start to the seedlings, apply 25–30 kg, calcium ammonium nitrate in the nursery. The seedlings are uprooted and transplanted after three weeks. While uprooting the seedlings, keep the nursery wet just to avoid root injury. Remove the top portion above the growing point so as to minimise the transpiration from the seedlings. Transplanting

should be done preferably on rainy days. If it is not raining, irrigate the field to help the seedlings to establish themselves. Transplant one seedling per hole in rows keeping 50 cm space between rows and 10 cm space between plants. Transplanting from third week of July to second week of August gives good results.

MANURES AND FERTILISERS

The fertiliser requirement of local varieties of Pearl millet can easily be met by the application of 10–15 tonnes of compost or farm yard manure/ha. But the nutrient supply for the high-yielding varieties and hybrids should be supplemented with inorganic fertilisers. Amount of fertiliser should be given on the basis of soil test value for maximum profit. General recommendations based on experimental findings are 100–120 kg nitrogen, 40–60 kg P_2O_5 and 30–40 kg K_2O /ha. Half of the above doses should be applied under *barani* (rainfed) conditions and for local varieties such as Manupur local for better results. Half dose of nitrogen and full doses of phosphorus and potassium should be applied at the time of sowing in furrows approximately 3–5 cm below the seed. This can be done by placing fertilisers through a funnel and dropping the seed in the same furrow by hand wherever seed-cum-fertiliser drills are not available. The remaining nitrogen is top dressed in two splits, one at the time of thinning (three to four weeks after sowing) and rest at ear formation stage. This dose of nitrogen can be withheld if moisture is limiting. In *barani* conditions foliar spray of 3% urea is also recommended.

WATER MANAGEMENT

As Pearl millet is a rainfed crop, there is hardly any need for irrigation. Irrigate the crop if there are no rains. Generally, two irrigation during the growing period of the crop are enough. If moisture is limiting irrigation must be done at the time of earhead emergence because it is the most critical stage for moisture stress. Pearl millet does not tolerate waterlogging. So, do not allow rain water to stand in the field for more than a few hours. Proper arrangement for draining the excess water must be made.

WEED CONTROL

Being a rainy season crop it suffers due to infestation of weeds. The damage is severe during 3–5 weeks after sowing. Therefore, timely control of weeds is essential to get higher yields. Interculture the crop three to five weeks after sowing. Avoid deep hoeing near the plants, so that their roots are not damaged. A wheel hoe, triphali or hand hoe can be used for interculture. However, sometimes due to unavailability of labour or soil being too wet to permit manual weeding, timely weeding becomes difficult. Under such circumstances the only effective way to control weeds is the use of herbicides. Pre-emergence application of Atrazine @ 0.5 kg active ingredient/ha in 800 L of water controls most of the monocot and dicot weeds.

DISEASES

Among the various factors responsible for low production of Pearl millet, diseases are major limiting factors. Symptoms of important diseases and their suitable control measures are given as follows.

Downy Mildew or Green Ear Disease

This disease is caused by *Sclerospora graminicola*. The symptoms of disease may be seen at an early stage on leaves. Infected leaves become yellow or white and downy with yellowish longitudinal streaks extending from the tip to the base. Such leaves soon turn brown and tear off at the streaks. The fungus growth can be seen on the lower surface of leaves in humid weather. The most distinguishing symptom of disease is transformation of ears into leafy whorl-type structures. The name green ear disease is derived from this stage of the disease.

Monitoring

- Visit the crop 25 days after sowing and then weekly if crop is intended for seed productions.
- Early symptoms to look for are chlorotic stripes on the leaves associated with stunting; these stripes later turn brown. Such plants should be removed.
- Infected plants may also become stunted and leafy structures can be seen on the ears.

Control Measures

- Avoid sowing millet in severely infected fields in the next 3 years because the pathogen is host specific and can survive without its host for a maximum of 3 years.
- Use disease-free seed and effective removal of disease infested plant material in the field after harvest of the crop are essential to reduce the primary inoculum in the soil. Downy mildew-infected plant material should be burnt, or if feasible the field should be ploughed deeply to bury infected the plant material.
- Crop sown very early in the season generally has less downy mildew than that sown late in the season.
- Use of resistant cultivars is the most cost-effective method.

Ergot

This disease is caused by a fungus known as *Claviceps fusiformis*. This disease has become a very serious problem in most of the bajra growing areas. The consumption of the disease affected grains is injurious to human as well as cattle health due to toxic compounds present in 'ergots'. The disease first

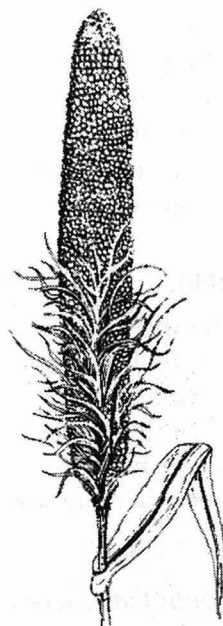


Fig. 5.2: Green ear disease of pearl millet (bajra)

appears on the ears in the form of honey-like pinkish liquid, which is full of fungus spores causing spread of the disease. The liquid turns brown and sticky. In the later stages, fungus sclerotia (ergots) appear as brown to black and elongate structures. They contain toxic alkaloids harmful to health. These sclerotia fall down in the field and remain in soil, causing infection in a subsequent crop.

Control Measures

- Deep ploughing soon after harvest helps bury sclerotia in a soil at a depth which prevents their germination, thus reducing primary inoculum.
- Separate infested seed from normal seed by soaking in 10% salt solution. Floating light weight infested seeds are separated from normal grain which sinks to the bottom.
- In India, two perennial grass weeds *Cenchrus ciliaris* and *Panicum antidotale* were found to harbor the pearl millet ergot fungus.
- Seed treatment with Metalaxyl-M 31.8% ES @ 2.0 ml/kg seed.
- Use of resistant cultivars is the most cost-effective method for the control of Ergot disease.

Smut

This disease is caused by *Tolyposporium penicillaria*. It is one of the important diseases affecting ears. The diseased kernels are green in the beginning and generally larger in size than healthy ones. These are full of fungal spores. The green colour is due to the green membrane surrounding the black mass of fungal spores. The colour of the membrane later turns to black.

Control Measures

- Use certified seed or treat the seed as mentioned earlier.
- Give deep ploughing during summer.
- Follow a three-year crop rotation.
- Spray the crop with 0.15% Vitavex (1.5 kg Vitavex mixed in 1000 L of water/ha) at boot leaf stage followed by one or two sprays at ten days intervals.

Rust

This disease is caused by *Puccinia substriata* var. *indica*. The disease is seen on both surfaces of leaves. The rust pustules are small, orange and full of spores. On touching these pustules, one can see orange coloured spores sticking on the fingertips. In later stages, black coloured pustules can be seen. In severe infection leaves are completely dried.

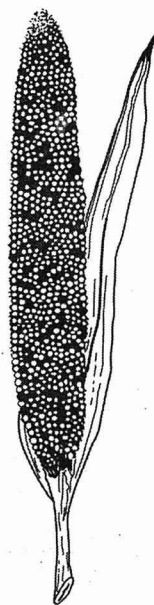


Fig. 5.4: Smut disease of pearl millet

Control Measures

- Rust causing fungi develop on many grass-weeds. These weeds help in spreading the disease to pearl millet crop. So, good weed control practice helps reduce the rust disease in pearl millet.
- Growing of rust resistant cultivars is advised in rust endemic areas.

Leaf Blast

This disease is caused by *Pyricularia grisea*. The symptoms of this disease can be seen on the lower surface in the form of light to dark brown, boat-shaped lesion. Sometimes several spots coalesce and form larger patches. In severe infection leaves are completely dried.

Control Measures

The disease can be controlled effectively by 2 or 3 sprays of 0.2% Zineb. Grow resistant varieties.

INSECT PESTS

Pearl millet crop is subject to attack by a number of pests. A brief description of the major ones, their nature of damage and suitable control measures are given as follows.

Termites

The pest feeds on the roots and lower portion of the stem of the plant. The attacked plants generally dry up. The pest is more serious in dry areas.

Control Measures

- Treat the seed at the rate of 1 g Cruiser 70 WS (thiamethoxam) or 4 ml Dursban/Ruban/Durmet 20 EC (chlorpyrifos) or 2 ml Neonix 20 FS (imidacloprid+hexaconazole) or 4 ml chlorpyrifos 20 EC per kg seed.
- Mix chlorpyrifos (1.5%) or quinalphos (1.5%) dust @ 25 kg/ha before sowing of crop
- In severe case, it can also be controlled by spraying the crop with imidacloprid 48 FS @ 1200 ml or imidacloprid 17.8 SL @ 350 ml.

White Grub

This pest is very serious. They damage the root system of young seedlings and as a result the seedlings die. In the areas where it is a problem, larvae cause the major damage resulting in the complete failure of crop.

Control Measures

- Place light traps @ 1 trap/ha between 7 PM and 10 PM after receipt of first monsoon rains.
- Deep summer ploughing to expose the pupae to scorching sun radiation and predation by birds.
- Use well-decomposed organic manures.

- Inter-cropping of pearl millet with pulses like green gram, cluster bean, and cowpea.
- Seed treatment with imidacloprid 17.8SL @ 2.0 ml/kg seed.
- Drench the root zone of crop with chlorpyrifos 20 EC @ 4.0 litres/ha or Ekalux (quinalphos 25EC) @ 3.5 litres/ha three weeks after the adult emergence.

Shoot Fly

Shoot fly is a serious pest of Pearl millet in north India. Plants up to 3 weeks of age are favourite of the pest. The fly lays eggs on the lower surface of the leaves or near the base of the plants. Within 2 days or so, the eggs hatch and the tiny maggots creep down under the leaf sheaths and cut the central growing point of the plant which results in the 'dead heart'.

Control Measures

As suggested in Sorghum.

Hairy Caterpillar

There are about seven species of hairy caterpillar that feed on Pearl millet crop. They are all polyphagous and feed on different crops. Among these Bihar hairy caterpillar, red hairy caterpillar, black hairy caterpillar are the major ones. The damage is done in the seedling and early stages of the crop. The adults lay eggs in clusters on the leaves of wild as well as cultivated plants. These eggs hatch within 3–4 days. The tiny larvae feed gregariously on the same plant for a few days and then move on to other plants and feed voraciously leaving only the veins of the leaves without any green material.

Control Measures

- Collect the egg masses and destroy them
- The light traps should be used as soon as moths are visible after rain starts
- Insect can also be controlled effectively by spraying cypermethrin 10 EC @ 650 ml or indoxacarb 15.8 EC @ 333 ml or 100 ml chlorantraniliprole 18.5 SC (Coragen) using 300 litres water.

Midge Fly

It is a serious pest of developing grains of Pearl millet. The fly lays eggs in the flowers and the larvae develop on their ovaries, which shrivel and fail to develop into grains. The larvae pupate in the spikelets.

Control Measures

- Plant pure and uniform seeds so that all plants come in flowering at same time
- Spray chlorpyrifos 20 EC @ 1.5 lit/ha or quinalphos 25 EC @ 1.5 lit/ha for its effective control.

Earhead Worm

A number of earhead worms feed on Pearl millet. The eggs are laid in the earheads. The larvae feed on developing grains and make a thick web of excretory pellets.

Control Measures

- For effective control of this pest, spray the crop with flubendiamide 39.35 SC (Fame) @ 100 ml or thiodicarb 75 WP (Larvin) @ 750 ml using 300 litres water.

HARVESTING AND THRESHING

Harvest the crop when grains are hard enough having about 20% moisture. Harvesting is done by cutting the entire plant or removing the earheads first and cutting down the plants later on. The earheads after harvesting should be dried well in sun before threshing. The grains are separated either by beating the earheads by sticks or by trampling by bullocks. The threshed grain should be cleaned and dried in sun to bring the moisture content down to 12–14% for safe storage.

YIELD

With improved cultural practices it is possible to harvest nearly 30–35 quintals of grain and about 100 quintals of dry stover from a hectare of crop under irrigated conditions and about 12–15 quintals of grain and 70–75 quintals of dry stover from a rainfed crop.

Barley

(*Hordeum vulgare* L.)

Barley is one of the most important cereals of the world. It is cultivated in almost all parts of the world except the tropical regions. Barley is a major source of food for large number of people living in the cooler semi-arid areas of the world, where wheat and other cereals are less well-adapted. It is a staple food of the people in Tibet, Nepal and Bhutan. In European countries it is used only as breakfast food. The leading countries of its production are Russia, China, France, Canada, USA and Spain.

Barley is an important cereal in India. Total area under barley in the country is about 0.57 million hectares. The chief barley growing regions in the country are higher Himalayas, central parts of eastern Uttar Pradesh, eastern parts of Rajasthan and north western parts of north Bihar.

The most important uses of barley in India are as grain feed to livestock and poultry, as malt for manufacture of beer and other liquors like whisky, brandy, etc. As a food barley flour is used in preparing 'chapatis'. Sometimes barley is mixed with gram or wheat and then ground to flour for preparing better quality 'chapatis'. Grain is roasted and ground and used as 'Sattu' (barley flour mixed in sugar and water). Grain is also broken and roughly ground into 'pearl' barley to be used in soup. Barley grain contains 12.5% moisture, 11.5% albuminoids, 74% carbohydrates, 1.3% fat, 3.9% crude fibre and 1.5% ash.

ORIGIN AND HISTORY

Barley has been known for thousands of years and it was cultivated before any recorded history of man. There are two theories regarding the origin of barley. One group of investigators considered Abyssinia as the principal centre of origin because many diverse forms grow wild there. This region is particularly rich in hulled, awned types. Another group of investigators considers that possible centre of origin is south eastern Asia, particularly China, Tibet and Nepal which is characterised by hull-less six-rowed varieties with short awn or no awn.

The barley must have been introduced to India soon after the coming of the Aryans. The Sanskrit name 'yava' which originally meant a grain, which was later limited to barley and, from which the name 'jau' or 'jav' has been derived shows that barley was in those very early days regarded as one of the most important grains.

All the cultivated forms of barley are thought to have arisen from a wild species *Hordeum spontaneum*, a species very similar to the present two-rowed barley. Archaeology also supports the two-rowed species as progenitor of six-rowed species.

AREA AND DISTRIBUTION

Barley is one of the important cereals of the world cultivated over an area of 51.2 million ha with production of 159 million tones with average productivity of 3108 kg/ha during 2019 (<http://www.fao.org/faostat>). The important barley growing countries are Russian Fed., Australia, Kazakhstan, Turkey, Canada, Spain, Ukraine etc. Russian Federation ranks first in acreage as well as production.

In India, cultivation of barley is done in about 0.59 million ha with a total production of 1.72 million tones with average productivity of 2920 kg/ha during 2019-20 (<https://www.indiastatagri.com>). Barley is cultivated in Rajasthan, Uttar Pradesh, Madhya Pradesh, Uttarakhand, Himachal Pradesh, and Haryana. Rajasthan is the largest producer of barley in India and alone produces more than half (58 percent) of barley followed by Uttar Pradesh (30 percent).

CLASSIFICATION

Aberg and Wiebe (1946) classified all the cultivated barley varieties into three distinct species based on the number of rows of grain and their arrangement:

- (a) *Hordeum vulgare*—six-row barley
- (b) *Hordeum distichon*—two-row barley
- (c) *Hordeum irregulare*—two-row barley

Hordeum vulgare: In this species all the three spikelets at each node of the spike are fertile. The spikelets are in six distinct rows and arranged at a uniform distance around the tough rachis. This species is cultivated in India.

Hordeum distichon: In this species only the medium spikelets are fertile and sets grain. Although the lateral spikelets are infertile, they possess all the floral organs. This species is also cultivated in India.

Hordeum irregulare: In this species central florets are fertile, whereas the lateral florets are reduced to rachilla.

BOTANICAL DESCRIPTION

Barley (*Hordeum* spp.) belongs to *Poaceae* (formerly called *Gramineae*) family. The barley plant very much resembles the wheat plant and usually grows 0.75 to 1 m in height. The botanical description of main parts of barley plant is given as follows.

Root System

It consists of shallow and deep roots. The shallow roots arise near the soil surface and spread out laterally about 15–30 cm almost at right angles to the tillers. The deep roots extend downwards into deep layers of soil. The depth of penetration varies 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 internodes are short at the base of the plant and the length increases from the base of the culm upwards. The nodes may be either exposed 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. They possess small ligule (0.5 to 3 mm). Auricles are very conspicuous, which partly or entirely clasp the stem and are much larger than those in wheat. The surface of leaf is rough. Two-rowed barleys have narrower leaves than six-rowed barleys.

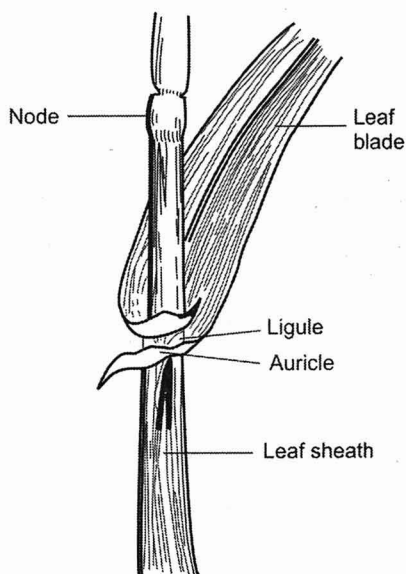


Fig. 6.1: Portion of barley culm

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 the glume awn is a very useful character of distinguishing varieties. The barley flower has three stamens, and a pistil with a single ovule and a 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 rachilla. 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.

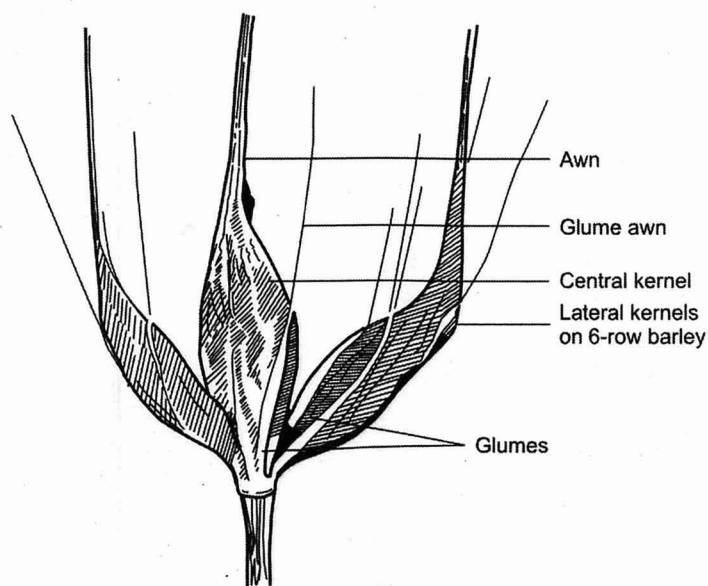


Fig. 6.2: Barley spikelet

CLIMATIC REQUIREMENTS

Barley requires cool weather during early growth and warm and dry weather at maturity. It grows fairly well in temperate 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 m altitudes. It is grown mostly in those regions where cultivation of wheat does not give economic yield.

SOIL

Barley thrives best on well-drained, fertile deep-loam soils. Being a salt tolerant crop, it can do well even in salt affected soils during the early phases of the reclamation of these soils. It gives higher yields than wheat and other cereal crops on moderately saline-alkali soils.

VARIETIES

A number of promising barley varieties have been evolved for cultivation under different production zones. These are furnished in Table 6.1. Salient features of important varieties are given in Table 6.2.

CROPPING SYSTEMS

Barley being a short duration crop is more suitable than wheat and other cereal crops for late sown conditions under limited inputs of irrigation and fertilisers.

Table 6.1: Promising barley varieties recommended for different agroclimatic zones

Zone/Region	Timely sown irrigated condition	Late sown irrigated condition	Rainfed condition	Salinity
North Western Plains Zone (NWPZ)				
Punjab, Haryana, western UP, Rajasthan	Priti (K 409), BH 393, RD 2592, NDB 1173, RD 2688, RD 2552, DWR 28, DWRUB 52, RD 2668, BH 902, DWRB 92, DWRB 101, RD 2794, RD 2849, DWRB 123	RD 2508, Malty (DL 88), DWRB 73, DWRUB 64, DWRB 91	Geetanjali, RD 2508, PL 419, NDB 4, RD 2624, RD 2660	RD 2552, NDB 1173, RD 2794
North Eastern Plains Zone (NEPZ)				
Eastern UP, Bihar, Odisha and West Bengal	Kedar (DL 36), Jagrati, RD 2503, Rekha (BCV 73), Ritambhara (K 551), K 603, HUB 113, BH 946	Narendra Barley 1 (NDB 209), Narendra Barley 3 (NDB 1020), Manjula (K 329), RD 2508	Haritma (K 560), Narmada (K 603), K 603	NDB 1173
Central Zone (CZ)				
Madhya Pradesh, Chhattisgarh	PL 751, RD 2715, BH 959	RD 2786		
North Hills Zone (NHZ)				
Hills of Jammu and Kashmir, Himachal Pradesh and Uttarakhand	BHS 400		Himadri (BHS 352), VLB 56, VLB 85, HBL 276, Gopi (HBL 316), BHS 352, BHS 380, UPB 1008, VLB 118, BHS 400	
Peninsular Plains Zone				
Maharashtra, Karnataka	Vijai (M 130), Malty (DL 88), Rekha (BCV 73)			

Source: ICAR—Indian Institute of Wheat and Barley Research, Karnal

Table 6.2: Distinguishing features of important barley varieties released in last 20 years

Variety	Year of release	Production condition	Salient features	Yield (q/ha)		Developed at
				Average	Potential	
RD 2552	2000	NWPZ, NEPZ for irrigated timely sown as well as for saline soils	Six-row hulled barley, tall plant height, high yielding and resistant to stripe rust, also suitable for saline soils, alkaline soils	44.06 (NWP) 38.37 (NEP)	61.00 45.98	RARI, Durgapura
K 603	2001	NEPZ for rainfed timely sown	Six-row hulled barley, pigmented basal stem, tall plant height and suitable for rainfed cultivation	29.07	38.40	CSAUA&T, Kanpur
DWR 28	2002	NWPZ for irrigated timely sown	Two-row malt barley, pigmented basal stem, developed lateral florets and bold yellow grains	41.40	52.70	ICAR-IIWBR, Karnal
BHS 352	2003	NH zone for rainfed timely sown	Six-row hullless barley, intermediate dense spikes with amber grains, good for food purposes, resistant to stripe rust	21.90	38.00	ICAR-IARI, RS, Shimla
RD 2624	2004	NWPZ for rainfed timely sown	Six-row hulled barley, tall plant height, elongated yellow grains and suitable for feed under rainfed cultivation	24.89	38.80	RARI, Durgapura
NDB 1173	2005	NWPZ and NEPZ for saline soils	Six-row hulled barley, pigmented basal stem, medium plant height and suitable for alkaline-saline soils	35.20	46.20	NDUA&T, Faizabad
RD 2660	2006	Rainfed cultivation in NWPZ	Six-row feed barley, pigmented basal stem, tall plant height and medium bold yellow grains	24.30	34.10	RARI, Durgapura
DWRUB 52	2007	Irrigated timely sown in NWPZ	Highly popular two-row malt barley, rudimentary lateral florets, medium plant height, high yielding resistant to stripe rust and leaf blight	45.10	58.40	ICAR-IIWBR, Karnal
RD 2668	2007	Irrigated timely sown in NWPZ	Two-row malt barley, drooping spikes, narrow leaves, large yellow grains and resistant to stripe rust	42.50	53.70	RARI, Durgapura

(Contd.)

Variety	Year of release	Production condition	Salient features	Yield (q/ha)		Developed at
				Average	Potential	
PL 751	2007	NWPZ, NEPZ for irrigated timely sown as well as for saline soils	Six-row hulled barley, pigmented basal stem, short to medium plant height and mented awns, suitable for feed barley	47.30	64.10	PAU, Ludhiana
RD 2715	2009	Irrigated timely sown in Central Zone for dual purposes	Six-row hulled barley, tall plant height and good forage yield, dual purpose barley (feed and forage purposes)	26.30 (GY) 171.6 (FY)	54.50 (GY) 335 (FY)	RARI, Durgapura
BH 902	2010	Irrigated timely sown in NWPZ	Six-row hulled barley, tall plant height, dense spikes, high yielding feed barley, bold grains and resistant to stripe rust	49.75	61.80	CCS HAU, Hisar
BHS 380	2010	Irrigated timely sown in NH Zone (dual purpose)	Six-row hulled barley, tall plant height, dense earheads and good forage yield under rainfed conditions, dual purpose barley (feed and forage purposes)	20.97 (GY) 49.4 (FY)	59.40	RARI, Durgapura
DWRB 73	2011	Irrigated late sown in NWPZ (LS, IR)	Two-row malt barley, medium plant height, rudimentary lateral florets, high 1000 grain weight, with resistance to stripe rust and leaf blights	38.70	53.18	ICAR-IIWBR, Karnal
UPB 1008	2011	Rainfed timely sown in NH Zone	Two-row hulled feed barley, narrow leaves, rudimentary lateral florets, medium size grains suitable for rainfed cultivation	26.44	35.00	GBPUA&T, Pantnagar
DWRUB 64	2012	Irrigated late sown in NWPZ	Six-row malt barley, pigmented basal stem, medium plant height and good resistant to stripe rust and leaf blights	40.50	61.20	ICAR-IIWBR, Karnal
DWRB 91	2013	Irrigated late sown in NWPZ	Two-row malt barley, pigmented basal stem, semi-erect spikes and nerve pigmented bold grains (high 1000 grain weight)	40.62	58.90	ICAR-IIWBR, Karnal
RD 2786	2013	Irrigated timely sown in central zone	Six-row hulled barley, tall plant height, long spikes, resistant to stripe rust but highly susceptible to spot blotch	50.20	61.40	RARI, Durgapura
VLB 118	2014	Rainfed timely sown in NHZ	Six-row hulled barley, tall plant height, long peduncle and medium bold yellow grains	30.84	50.00	ICAR-VPKAS, Almora

(Contd.)

Variety	Year of release	Production condition	Salient features	Yield (q/ha)		Developed at
				Average	Potential	
BHS 400	2014	Rainfed timely sown in NHZ	Six-row hulled barley, tall plant height, medium peduncle length, late maturing and elongated yellow grains	32.71	58.70	ICAR-IARI, RS, Shimla
DWRB 92	2014	Irrigated timely sown in NWPZ	Two-row malt barley, pigmented basal stem, developed lateral florets, pale green spikes, high 1000 grain weight and diastatic power	49.81	69.06	ICAR-IIWBR, Karnal
HUB 113	2014	Irrigated timely sown in NEPZ	Six-row hulled barley, tall plant height, elongated yellow grains and tolerant to stripe rust and spot blotch	43.20	63.77	BHU, Varanasi
BH 946	2014	Irrigated timely sown in NEPZ	Six-row hulled barley, tall plant height, nerve pigmented grains, high yielding and resistant to stripe rust	51.96	66.32	CCS HAU, Hisar
DWRB 101	2015	Irrigated timely sown in NWPZ	Two-row malt barley, rudimentary lateral florets, medium plant height, with good malting and brewing quality and resistance to stripe rust and leaf blights	50.1	67.44	ICAR-IIWBR, Karnal
BH 959	2015	Irrigated timely sown in CZ	Six-row hulled barley, pigmented basal stem, short to medium plant height and high yielding	49.9	67.5	CCS HAU, Hisar
RD 2794	2016	Irrigated timely sown in NWPZ and NEPZ under saline-sodic soils	Six-row hulled barley, tall plant height and suitable for saline-alkaline conditions for NWPZ and NEPZ	29.90	43.30	RARI, Durgapura
RD 2849	2016	Irrigated timely sown in NWPZ	Two-row malt barley, rudimentary lateral florets, good malting quality and resistant to stripe rust	50.9	69.2	RARI, Durgapura
DWRB 123	2017	Irrigated timely sown in NWPZ	Two-row malt barley, medium plant height, rudimentary lateral florets, pale green spikes with good malting and brewing quality and resistant to stripe rust and leaf blight	48.7	67.26	ICAR-IIWBR, Karnal

Source: Kumar et al., 2017

The crop can be grown successfully after the harvest of paddy, cotton, *Kharif* fodder, groundnut, etc. Barley is included in the following common cropping systems.

1. Rice-barley
2. Maize-barley
3. Sorghum-barley
4. Cotton-barley
5. Pearl millet-barley
6. Groundnut-barley
7. Blackgram-barley
8. Moong-barley
9. Cowpea-barley
10. Clusterbeam (Guar)-barley

Barley is grown mixed with crops like chickpea, mustard, linseed, etc.

FIELD PREPARATION

A good seed bed is required for raising the barley crop, though the land preparation required is not as thorough as that for wheat. Barley is mostly grown on light soils where four to five ploughings with local plough or three to four harrowings followed by planking are sufficient to prepare a good seed bed. However, in rainfed areas field preparation should be done with great care as conservation of moisture is dependent on it. In these areas ploughing or harrowing should be done in the evening time and furrows should be kept open whole night to absorb moisture from dew. Planking should be done early in the morning. In areas where crops are attacked by termites, mix chlorpyrifos 1.5% dust in soil @ 25 kg/ha at the time of last ploughing.

SEED AND SOWING

For sowing in rainfed and saline areas soak the seeds in water overnight at room temperature for better and quicker germination. Under irrigated normal conditions soaking of seeds is not required. Before sowing, the seed should be treated with 1 : 1 mixture of Thiram + Bavistin or Vitavax @ 2.5 g/kg of seed.

Time of Sowing

Time of sowing is an important aspect in successful cultivation of barley. Barley gives best results when sown between October 15 and November 15. There is a gradual decline in yield when sowing gets progressively delayed up to the end of December. In rainfed areas sowing should be done in third and fourth week of October. In irrigated areas sowing should be done in first and second week of November.

Seed Rate and Spacing

Seed rate varies according to agro-conditions. In irrigated areas for normal sowing 75 kg seed/ha is sufficient while in late sown conditions seed rate should be increased to 100 kg/ha. Under rainfed conditions 80–100 kg seed/ha is required depending on soil moisture availability. For saline soils use 100 kg seed/ha to ensure better stand of the crop.

For normal sown irrigated crop a spacing of 22.5 cm between rows is recommended. Sowing should be done at a depth of 4–5 cm. In rainfed crop a spacing of 23–25 cm between rows is recommended. Sowing should be done at a depth of 6–8 cm depending upon soil moisture.

Method of Sowing

Method of sowing is an important aspect particularly under rainfed conditions. Seed should be dropped with the help of 'Pora' or 'Nai' attached to a local plough, or with the help of seed drill to ensure uniform distribution of seed at the optimum depth. In irrigated areas seed may be sown by 'Kera' method, where seed is dropped by hand into the furrows. There should be enough moisture in soil for proper germination.

MANURES AND FERTILISERS

Manures and fertilisers both play important roles in barley cultivation. When barley is grown as an irrigated crop, about 10–15 tonnes of compost or farm yard manure could be applied about a month before sowing. The application of organic matter to soil improves water holding capacity of the soil besides providing essential nutrients to the plants.

The quantity of fertilisers to be applied varies according to the fertility status of the soil. However, when soil test data is not available, apply fertilisers as below:

- (a) Irrigated 80 kg N, 50 kg P_2O_5 and 50 kg K_2O /ha.
- (b) Rainfed 50 kg N, 30 kg P_2O_5 and 30 kg K_2O /ha.
- (c) Late sowing 40 kg N, 30 kg P_2O_5 and 20 kg K_2O /ha.

Half of the nitrogen and total amount of phosphorus and potash should be applied at the time of sowing. The remaining half quantity of nitrogen should be top-dressed at the time of first irrigation. In rainfed crop the whole amount of nitrogen and phosphorus and potash should be applied 8–10 cm deep in furrows at the time of sowing.

WATER MANAGEMENT

Barley is generally grown as rainfed crop because it has low water requirement. It needs two to three irrigations to give good yields. One extra irrigation shall be required on sandy soils. If supply of water is inadequate, its efficiency should be increased by applying it at critical stages of growth. If only one irrigation is available, it should be given near active tillering stage (30–35 days after sowing).

When two irrigations are available, one should be applied at active tillering and the other at flowering stage.

On highly saline and sodic soils, frequent light irrigations give better results than fewer heavy irrigations.

WEED CONTROL

Weeds are usually a problem only in irrigated areas. The major weeds are *Chenopodium album* (bathua), *Cirsium arvense* (kateli), *Anagallis arvensis* (Krishna neel), *Melilotus alba* and *Melilotus indica* (senji) and *Avena fatua* (wild oat). It is desirable to control the weeds through the use of good cultural practices. Broadleaved weeds can be controlled by an application of 2,4-D sodium salt (80%) or 2,4-D amine salt (72%) at 0.75 kg a.i./ha in 700–800 L of water/ha, 35–40 days after sowing of the crop. Under rainfed conditions the rate of herbicide should be slightly lower, i.e. 0.5 a.i./ha.

For the control of *Phalaris minor* and wild oat (*Avena fatua*) spray Pyroxasulfon 150 g in 500 L of water or Pendimethalin + Metribuzin 2.5 L in 500 L of water within two days of sowing.

DISEASES

Barley crop suffers from several diseases which reduce its yield. Symptoms of important diseases and their suitable control measures are given as follows.

Stripe Disease

This disease is caused by fungus *Drechslera graminea* Rabh. It is a common disease throughout the barley growing regions particularly in humid and semi-humid regions. It is a serious disease particularly in Bihar and Uttar Pradesh. Low temperature and high humidity are conducive for disease development. The symptoms start appearing from the late tillering stage and continue up to maturity. Yellow strips show up on the older leaf blades and sheaths as initial symptoms. Later the stripes turn brown as the tissue dries up and the leaf blade becomes shredded in advance stage of the disease. In case of severe infection the spike emergence is adversely affected. Very few grains are produced in the earhead of affected plants. It lowers the yield and impairs the quality.

Control Measures

- Sow only thoroughly cleaned, certified seed from disease-free source.
- Practice clean cultivation.
- Soak the seeds in cold water from 6 to 10 a.m. on a bright sunny day in April or May and then expose to sun on a brick floor from 10 a.m. to 5 p.m. when the temperature of the floor is about 40–45°C. The high temperature kills the fungus rendering seed free from infection.
- Where practical, control susceptible grasses and other weeds by cultural or chemical means.

Net Blotch Disease

The disease is caused by *Helminthosporium feres* Sacc. The initial symptoms on the seedling leaf are the development of brown reticulata blotches at or near the tip of the blade. Local lesions on the young leaves may develop at any stage between seedling stage to maturity. The blotches coalesce longitudinally resulting in dark brown strips with irregular margins.

Control Measures

- Time of sowing: Early sowing increases the risk of a net blotch infection. However, sowing later to avoid net blotch should be weighed up against other agronomic factors.
- Seed treatment as discussed above.
- Crop rotation: Avoid growing barley in successive years in the same paddock as most inoculum survives in stubble.

Spot Blotch Disease

This disease is caused by *Helminthosporium sativum* pam. The dark brown to black lesions usually occur first on the coleoptile and progress inward. The seedling leaves of infected plants are dark green, seedling growth is retarded and tillering is excessive. Elongated brown spots appear on leaves, glumes and spikelets, ears are poorly filled and grain shrivelled.

Control Measures

- (a) Treat the seed as mentioned earlier.
- (b) Crop rotation and field sanitation can minimise the inoculum build up.

Rusts

Rusts are responsible for colossal losses in barely crop. These are of three kinds, viz. yellow rust, brown rust and black stem rust. Yellow rust is the most destructive of all the rusts which attack barley.

- (a) *Yellow rust*: This rust is caused by *Puccinia glumarum*. The linear citron-yellow uredia appear on leaf blades. Frequently, the uredia unite end to end to form narrow stripes extending considerable distance on the leaf blades and sheaths of susceptible varieties. The arrangement of uredosori in linear fashion forming long stripes and lemon yellow colour of the uredia are the main diagnostic symptoms of this rust.
- (b) *Brown rust*: This rust is caused by *Puccinia hordei* Otth. It is a minor disease and occurs rarely at irregular intervals. Round to slightly oblong pustules which are brown or orange in colour usually appear on the leaf blades and are less common on leaf sheaths and stalks. These are irregularly scattered but sometimes appear in clusters on the leaf blade but never in rows or stripes as in case of yellow rust.
- (c) *Black stem rust*: This rust is caused by *Puccinia graminis tritici*. Reddish-brown to dark brown and oblong pustules appear on culms and leaf-sheaths. Pustules later turn black. Shrivelling of grains occur. Losses in

yield are not appreciable due to the fact that the rust does not appear before March in the northern barley belt.

Control Measures

- (a) Cultivation of rust resistant varieties like DWRUB 52, BH 902, DWRB 73, HUB 113, DWRUB 64, DWRB 91, BH 946, DWRB 123, etc. offer the best control.
- (b) Four sprays of Zineb @ 2 kg/ha or Propiconazole (Tilt) 25 EC @ 1 L/ha in 700–800 L of water, at fortnightly intervals offer an effective control.

Powdery Mildew

This disease is caused by a fungus *Erysiphe graminis*. It develops as a powdery growth over the surface of leaf, leaf-sheath and floral bracts. The superficial mycelium and conidia are first light grey in colour. Mycelium darkens with age and later numerous round and dark cleistothecia develop. The characteristic symptom is the gray powdery surfaced lesions scattered or completely covering the leaf blade with yellowing, browning, and gradual drying out of the leaf tissue.

Control Measures

- (a) Sulphur dusting @ 15–20 kg/ha offers an effective check.
- (b) Three sprays of Karathane (0.2%) at intervals of 15 days control the disease.
- (c) Cultivation of resistant varieties offers a good control.

Smuts

Barley is attacked by loose and covered smut.

1. *Loose smut*: This disease is caused by *Ustilago nuda*, and is internally seed borne. Infected grains cannot be differentiated from the healthy ones. Internally seed borne mycelium gets activated with the germination of seed and grows with the growing points of the plant. Thus, the fungal hyphae produce the smut spores in the grain which is full of black powdery mass. Instead of healthy grains, the smutted grains appear. In due course of time, the membrane enclosing the smut spores ruptures releasing the spores.

Control Measures

- (a) Treat the seed with systemic fungicide such as Vitavax @ 2.5 g/kg of seed.
 - (b) Pick-up the diseased earheads before rupture of the membrane in paper bags and burn them.
 - (c) Soak the seed in cold water for four hours (6–10 a.m.) on a bright sunny day in May or June and then expose to sun on a brick floor from 10 a.m. to 5 p.m. when the temperature of the floor is about 40–45°C. The fungus mycelium inside the seed is inactivated and killed.
2. *Covered Smut*: This disease is caused by *Ustilago hordei* Pers. The disease first becomes noticeable at heading time, when smutted heads emerge from the boot. The hard, black masses of smut along the axis of the affected heads are

enclosed with rather persistent membrane. Smut sori are generally broken in threshing, thus releasing the spores which cling to the healthy seeds.

Control Measures

- (a) Seed treatment with Vitavax @ 2.5 g/kg of seed offers a complete control.
- (b) Grow resistant varieties.

Molya Disease of Barley

This disease is caused by a nematode *Heterodera avenae*. It occurs in small patches. Due to this disease plants are stunted in growth, leaves are discoloured to yellow and often become reddish from the tip. Tillering is also reduced. The growing point of root is inhibited and often killed. The plants produce new roots near this point causing a resetting effect.

Control Measures

- (a) Adopt crop rotations of three to four years with non-cereal crops.
- (b) Two or three deep ploughings during summer will also reduce the nematode population.
- (c) Grow resistant varieties like RD 2035, Karan 16, etc.
- (d) Application of Carbofuran @ 25 kg/ha helps in suppressing nematode in the soil.

INSECT PESTS

Barley crop is attacked by a number of insect pests and rodents. Some of the most important and common ones are given as follows.

Soil Insects

There are a number of soil insects that damage the crop soon after sowing. The damaged plants dry up completely causing poor crop stand. The important soil insects are white ants (*Odontotermes obsesus*) termites (*Microtermes indicus*), Gujhia weevil (*Benymercus indicus*) and cutworms (*Agrotis* spp.).

Control Measures

For effective control, spray thiamethoxam 25 WG (Actara) @ 100 g/ha or oxydemeton methyl 25 EC (Metasystox) or dimethoate 30 EC (Rogor) @ 1000 ml/ha or chlorpyrifos 20 EC @ 1.5 litres/ha by using 500–600 litres of water per hectare.

Foliage Pests

These are minor insects of wheat causing discolouration of leaves. It is of very small size and attack is more observed on rainfed barley. However, to control these pests, spray cypermethrin 10 EC @ 650 ml or indoxacarb 15.8 EC @ 300 ml or 100 ml chlorantraniliprole 18.5 SC (Coragen) using 300 litres water.

Rodents

Field rats cause heavy loss to barley crop and do considerable damage to the harvested crops lying in stacks in the field. For rat control fumigate live-burrows with aluminium phosphide @ 1 tablet of 0.5 g/small burrow, and 3.0 g/large burrow. In case of reappearance in the same field, bait with coumatetallyl (Ratafin) @ 1 kg of prepared bait (1 part coumatetallyl: 19 parts wheat or maize flour, 1 part molasses and 1 part mustard oil).

HARVESTING AND THRESHING

The crop should be harvested immediately after it ripens otherwise it might lodge and shatter grains. This crop shatters more easily than does wheat. It should be harvested in the forenoon before the heads become too dry and fragile for handling. Harvesting of crop is done with sickle by manual labour. Threshing is done either by trampling bullocks or by stationary threshers.

YIELD

When cultivation of high-yielding varieties of barley is done with improved scientific methods, they produce about 30–35 quintals of grain and 40–45 quintals of straw/ha.

Finger Millet (Mandua)

(*Eleusine coracana* Gaertn)

Mandua or ragi, known in English as 'finger millet', is an important minor millet grown in India. It is a staple food crop in many hilly regions of the country. This crop is cultivated up to an altitude of 2100 m above the sea level. In fact, it is the main cereal crop for monsoon season in some hill areas. It is grown both for grain and forage. In northern hills, grains are eaten mostly in the form of 'chapatis'. 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. Mandua grain contains 9.2% protein, 1.29% fat, 76.32% carbohydrates, 2.24% minerals, 3.90% ash and 0.33% calcium. Besides vitamins A and B, phosphorus is also present in smaller quantities. 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. The finger millet, a major contributor to the sustenance of production level, accounts for about 50% area and 65% production under small millets.

ORIGIN AND HISTORY

According to DeCandolle (1886) finger millet (mandua) probably originated in India, as many of the forms exist in this 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 Abyssinia and rest of Africa (Vavilov, 1951), Mehra (1962) considers *Eleusine coracana* to be of African origin.

AREA AND DISTRIBUTION

Mandua or finger millet is widely cultivated in India, Africa, Ceylon, Malaysia, China and Japan. In India, it is cultivated over an area of one million hectares with total production of about 1.76 million tones with an average productivity of 1747 kg/ha during 2019-20 (<https://www.indiastatagri.com>). The major finger millet growing states are Karnataka, Tamil Nadu, Uttarakhand, Maharashtra and Odisha.

BOTANICAL DESCRIPTION

Finger millet is an erect, tufted annual, growing to 60–122 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 round nodes. The leaves are linear with distinct midrib, ligule and a fringe of hairs. The tillers bear at the end of the culm earheads which consists of a whorl of finger like spikes (2–8 in number) in which spikelets are arranged closely on both sides of a slender rachis. The spikelets 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 reddish-brown in colour. Finger millet belongs to *Poaceae* family.

CLIMATIC REQUIREMENTS

Finger millet (*mandua*) is a crop of tropical and subtropical climate and can be grown successfully from sea level to an altitude of 2100 m on hill slopes as well as in plains. It is a very hardy crop. It is grown in areas having annual average rainfall between 50 and 100 cm. 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.

SOIL

Finger millet (*mandua*) can be grown on a wide variety of soils ranging from very poor to very fertile soils. It thrives best on well-drained loam or clay loam soils. Clayey soils, heavy black cotton soils, gravely and stony soils with poor fertility and drainage are not suitable for raising *mandua* crop. It tolerates salinity better than other cereals.

VARIETIES

There are some improved varieties of finger millet (*mandua*) suitable for growing in different states. These are furnished in Tables 7.1 and 7.2.

CROPPING SYSTEMS

Finger millet (*mandua*) under rainfed conditions is grown mixed with sorghum, Pearl millet and a variety of oilseeds and pulses. In hills it is grown mixed with soybean. Under irrigation it is grown in rotation with several crops like tobacco, chillies, vegetables, turmeric and crops like chickpea, linseed, mustard, barley, etc. Some of the common cropping systems are given as follows:

North India

1. Finger millet—chickpea
2. Finger millet—barley
3. Finger millet—mustard
4. Finger millet—linseed
5. Finger millet—tobacco

South India

1. Finger millet (ragi)—groundnut
2. Finger millet (ragi)—tobacco
3. Finger millet—sugarcane
4. Finger millet—potato—maize
5. Finger millet—potato—finger millet

Table 7.1: Promising finger millet (mandua) varieties for different states

Sl. No.	Crop/Variety	Institute where developed	Year of release	Maturity (days)	Average yield (Q/ha)	Area of adaptation	Special features
1	VL 376	ICAR-VPKAS, Almora	2016	103-109	29-31	All Ragi growing areas of country	Responsive to fertilizer and moderately resistant to blast
2	GNN-6	Waghai, Navsari	2016	120-130	28-30	Gujarat	Moderately resistant to leaf blast and finger blast
3	GN-5	Agricultural University Waghai, Navsari	2016	120-130	25-27	Gujarat	Late maturing, white colour seed, moderately resistant to leaf and finger blast
4	VL Mandua-348	ICAR-VPKAS, Almora	2016	104-112	18-20	Uttarakhand	Suitable for organic cultivation, resistant to neck and finger blast, and tolerant to lodging, light copper grains
5	KMR 340	VC Farm, Mandya, UAS, Bengaluru	2016	90-95	35-40	Karnataka	White ragi variety, specially for confectionary purpose, resistant to blast and blight diseases, tolerant to stem borer and aphids
6	OEB 532	OAUT, Bhubaneswar	2012	110-115	22-35	Odisha, Bihar, Chhattisgarh, Karnataka, Tamil Nadu	Moderately resistant to blast diseases, non-lodging and non-shattering
7	KMR 204	VC Farm, Mandya, UAS, Bengaluru	2012	100-105	30-35	Karnataka	Early duration variety
8	VR 936	ANGRAU, Vizianagaram	2012	115-120	28-30	Andhra Pradesh	Suitable for late conditions, responsive to nitrogenous fertilizers
9	PPR 2700 (Vakula)	ARS Perumallapalle, AP	2012	105-110	25-30	Andhra Pradesh	Resistant to leaf blast and tolerant to drought
10	Indira Ragi 1	Jagdarapur, IGK VV	2012	120-125	25-26	Chhattisgarh	Non-shattering, non-lodging, responsive to fertilizers

(Contd.)

Sl. No.	Crop/Variety	Institute where developed	Year of release	Maturity (days)	Average yield (Q/ha)	Area of adaptation	Special features
11	VL 352	ICAR-VPKAS, Almora	2012	95-100	33-35	All Ragi growing areas of country	Moderately resistant to blast
12	KOPN 235	MPK VV, Rahuri	2011	115-120	25-26	Sub-mountain and ghat zone of Maharashtra	Resistant to blast
13	OEB 526	OAUT, Bhubaneswar	2011	110-115	25-26	Odisha, Bihar, Chhattisgarh, Karnataka, Tamil Nadu	Moderately resistant to leaf, neck and finger blast diseases
14	GPU 66	PC Unit, Bengaluru	2009	112-115	35-40	Karnataka	Green plant parts with narrow leaves, medium compact ears with tip incurved fingers
15	GPU 67	PC Unit, Bengaluru	2009	114-118	30-35	National	Non-lodging (semi-dwarf)
16	Srichaitanya (VR 847)	ANGRAU, Vizianagaram	2009	110-115	26-28	Andhra Pradesh	Moderately resistant to blast
17	KMR 301	VC Farm, Mandya, UAS, Bengaluru	2009	120-125	55-60 (irrigated) 35-40 (rainfed)	Southern dry zone of Karnataka	High grain and straw yield, tolerant to blast
18	PRM 1	Hill Campus, GBPUA&T, Ranichauri	2006	110-115	20-25	Hills of Uttarakhand	Resistant to blast
19	Bharathi (VR 762)	ANGRAU, Vizianagaram	2006	110-115	26-30	Andhra Pradesh	Moderately resistant to blast
20	GPU 48	PC Unit, UAS, Bengaluru	2005	95-100	30-35	Karnataka	Early, high yield, blast resistant, suitable for summer also
21	GPU 48	PC Unit, Bengaluru	2005	95-100	28-30	Karnataka	Pigmentation on all plant parts and highly resistant to blast

Source: ICAR—Indian Institute of Millets Research (IIMR), Hyderabad

Table 7.2: Biofortified varieties of finger millets

Name	Biofortified attributes	Grain yield, dry fodder yield (Q/ha)	Maturity (days)	Adaptation	Developed
VR 929 (Vegavathi)	Rich in iron (131.8 ppm) in comparison to 25.0 ppm in popular varieties	36.1, 72.0	118	Kharif season across country	Acharya NG Ranga Agricultural University, Guntur
CFMV1 (Indravati)	Rich in calcium (482 mg/100 g), iron (58.8 ppm) and zinc (44.0 ppm) in comparison to 200 mg/100 g calcium, 25 ppm iron and 16 ppm zinc in popular varieties	31.1, 84.4	110-115	Suitable for rainfed condition. Kharif season in Andhra Pradesh, Tamil Nadu, Karnataka, Puducherry and Odisha	ARS, ANGRAU, Vizianagaram
CFMV 2	Rich in calcium (454 mg/100 g), iron (39.0 ppm) and zinc (25.0 ppm) in comparison to 200 mg/100 g calcium, 25 ppm iron and 16 ppm zinc in popular varieties	29.5, 86.1	119-121	Suitable for rainfed condition. Kharif season in Andhra Pradesh, Chhattisgarh, Gujarat, Maharashtra and Odisha	Hill Millet Research Station, Navsari Agricultural University, Waghai

Source: Yadava et al, 2020

FIELD PREPARATION

The field for finger millet (*mandua*) crop is prepared as thoroughly as possible. The first ploughing with mould board plough should be done immediately after the harvest of the previous crop. In south India, where the soil becomes too hard for ploughing, a shallow stirring should be given by heavy 'kunte' (bladed harrow) or a disc harrow. With the onset of monsoon, field should be harrowed or ploughed with local plough two to three times and finally levelled. In south India under rainfed conditions, with every succeeding rain the ploughing is repeated or the 'kunte' is used. Seed bed for *mandua* is usually very thoroughly prepared, which should be free of weeds, friable and smooth for better germination and crop growth.

SEED AND SOWING

Time of Sowing

The irrigated crop of finger millet is sown in more than one season in Karnataka, Tamil Nadu and Andhra Pradesh. The rainfed early crop is sown in April or early May. *Kharif* season main crop is sown during May or June. If the rains are not received in time the sowing time is shifted forward up to the end of August. However, sowing should be done early in rainfed conditions to avoid moisture stress at critical stage of flowering. In areas, where irrigation facilities are inadequate, the sowing should be done soon after the onset of monsoon. In higher hills of north India the optimum time of sowing for *mandua* is first fortnight of June.

The irrigated crop in *Rabi* season in Karnataka, Tamil Nadu and Andhra Pradesh is sown in September and October.

Seed Rate

The quantity of seed required would be between 8 and 10 kg/ha in case of line sowing. When crop is raised by transplanting, four kg seed is sufficient for raising nursery. Seed should be treated with Thiram @ 2.5 g/kg of seed.

Method of Sowing

It is beneficial to sow *mandua* in lines 3–4 cm deep. Line sowing ensures better germination, cuts down seed requirement and facilitates intercultural operations as compared to broadcast method of sowing. Line to line distance of 20–25 cm and plant to plant distance of 8–10 cm are considered ideal for *mandua* crop.

In areas with adequate moisture, *mandua* can be raised by the method of transplantation. Higher yields are obtained in case of transplanted crop as compared to direct seeded crop. Transplanted crop does not lodge during rains. Seed should be sown in well-prepared nursery beds during the month of May–June. About 4 kg seed of *mandua* will give enough seedlings to transplant

one hectare of land. Three to four weeks' old seedlings should be transplanted in the main field. Before pulling the seedlings, the nursery should be irrigated. Field should be well-prepared before transplanting. Transplant two seedlings per hill at a distance of 25×8 cm or 20×10 cm. Seedlings should be transplanted 2–3 cm deep. The beds should be irrigated on the third day after transplantation. In the absence of timely rains, transplanted field should be irrigated regularly till the seedlings are well-established. Other cultivation practices for transplanted crop are similar to that for direct sown crop.

MANURES AND FERTILISERS

Addition of adequate quantities of organic matter in mandua soils is considered beneficial, since it helps to improve physical condition of soil which helps soil to retain moisture for a longer period of time. Apply about 5 to 10 tonnes of farm yard manure or compost/ha one month before sowing. Fertilisers should be applied according to soil test recommendations. If soil test values are not available, apply as shown in Table 7.3. Entire amount of phosphatic and potassic and half of nitrogenous fertiliser should be applied at sowing time. Half of the remaining dose of nitrogen should be top dressed in two equal split doses after 30 and 50 days of sowing. The entire quantity of fertilisers should be applied 8–10 cm deep in soil at the time of sowing.

Table 7.3: Recommended fertiliser doses for finger millet in different states

State	Fertilisers dose N : P : K (kg/ha)	
	Rainfed	Irrigated
Andhra Pradesh	40 : 20 : 20	90 : 30 : 20
Bihar	40 : 20 : 20	60 : 30 : 20
Gujarat	80 : 40 : 0	—
Himachal Pradesh	40 : 20 : 0	—
Karnataka	50 : 40 : 25	100 : 50 : 50
Maharashtra	25 : 20 : 0	50 : 25 : 0
Madhya Pradesh	40 : 40 : 0	—
Odisha	40 : 20 : 20	60 : 20 : 20
Tamil Nadu	60 : 30 : 30	90 : 45 : 45
Uttar Pradesh	60 : 30 : 0	—
Uttarakhand	40 : 20 : 0	—

WATER MANAGEMENT

Finger millet sown during *Kharif*, generally does not need any irrigation. However, at tillering and flowering stages, if rains stop for a long spell, then irrigation would be required to obtain good yield. Furrows and ridges should be prepared for irrigation, which would serve dual purpose of irrigation and drainage. Finger millet crop does not do well under water logged conditions, therefore, proper removal of excess water after rains is also essential.

WEED CONTROL

It is essential to control weeds in the initial stage of plant growth and development. The intercultivation and weeding should be done with hand hoe after 25 days of sowing. Two to three hoeings would be sufficient to control the weeds in problem areas.

DISEASES

The main diseases of finger millet are blast, seedling blights, downy mildew and smut.

Blast

This disease is caused by a species of *Piricularia fungi*. Infection of this disease may occur even in seedling stage with grey-green to yellow lesions forming on leaf blades. In a severe condition, spots may coalesce to form large blighted spots and mainstem becomes infected and the earheads break over. Grain of infected earheads is shrivelled and become light in weight.

Control Measures

- Use disease-free seeds.
- Use of resistant varieties/genotypes like CO RA (14), Paiyur (RA)-2, GPU-26, GPU-28, GPU-45, GPU-48, L-5, VL-149, VL-146, PES 8, PES 176 Gautami, etc.
- Good sanitary practices are essential to limit the spread of the disease.
- Proper plant spacing and transplanting is advisable.
- Early sowing (July month) reduces the blast severity.
- Seed treatment with *Trichoderma harzianum* and one spray of *Pseudomonas fluorescens* at the time of flowering and second spray after 10 days control blast disease.

Seedling Blight

This disease is caused by a fungus *Drechslera nodulosum*. It causes severe damage during years with high continuous rainfall. This disease occurs throughout the life cycle of finger millet plant and may infect all parts of the plant.

Control Measures

- (a) Seed treatment with organo-mercurials like Ceresan or Thiram, etc.
- (b) Spray the crop with 0.2% Zineb.
- (c) Destroy plant debris.

Downy Mildew or Green Ear Disease

The disease is caused by *Sclerophthora macrospora*. Affected plants are generally stunted with shortened internodes and profuse tillering. The plant assumes a bunchy and bushy appearance. Often, pale yellow translucent spots are seen on leaves of affected plants. The white cottony growth, characteristics of many

downy mildews, is generally not seen in the downy mildew of finger millet. Partial or whole ear including lemma palea and glumes change into leafy structures. Finally the whole ear gives a bush-like appearance displaying typical 'green ear' symptom.

Control Measures

- Rogue out infected plants, when found in the field; treat seeds with an appropriate systemic fungicide prior to planting and continue to spray the crop at least once every 25 days after sowing.
- Providing good drainage in the low lands, proper crop rotation methods, elimination of wild grasses and related hosts will reduce the disease incidence.

Wilt or Foot Rot

The disease is caused by *Sclerotium rolfsii*. The infected plants become pale, chlorotic and stunted. The infection occurs just above the ground in collar region. Profuse cottony mycelial growth of the pathogen can easily be seen in this area. Soon small roundish white velvety grains like sclerotial bodies start appearing in the fungal matrix which grow and later turn brown. Meanwhile the leaves loose, droop and dry. Ultimately the plant dries up prematurely.

Control Measures

- The ideal way of managing disease is cultural methods like deep ploughing before sowing, crop rotation with non-graminaceous crops and maintaining optimum soil conditions, etc.
- Use of resistant varieties/genotypes like GPU 28, RAU 8, L-49-1, MR 6, OEB 82, PR 202, OEB 10, etc.

Cercospora Leaf Spot

Disease is caused by *Cercospora eleusine* and is a serious disease in mid and high hills, where rainfall is high and mean daily temperature does not exceed 20°C. The disease has been found to occur in Uttarakhand hills. The disease occurs most severely in the month of June in the early sown crop. Infection generally starts from the older leaves and then spreads to the young leaves. Initial symptoms appear as reddish brown speck with yellow halo. Later, several such specks coalesce to form large lesions with any yellow halo. Such leaves give burnt appearance. At the time of crop maturity several infected leaves turn completely necrotic, shrivel and dry.

Control Measures

- Field sanitation free from plant disease debris.
- Grow resistance genotypes.

Smut

The disease is caused by *Ustilago eleusine* and generally manifests itself few days after flowering. The smutted grains can be seen scattered randomly in

the ear head. The affected ovaries get converted into gall-like bodies which are several times bigger in size than the normal grains. Later the infected grains become swollen. The greenish outer tunica of the sorus gradually turns pinkish-green and finally turns to dirty black on drying.

Control Measures

- The disease is more common in late sown summer crop; early sowing in the month of January can avoid the disease.

INSECT PESTS

Among the few pests affecting this crop, aphids, hairy caterpillar, grass hoppers and earhead bugs are worth mentioning. Stem borers sometimes damage the crop severely. They may be controlled by using quinalphos 25 EC @ 1500 ml/ha. Bihar hairy caterpillar and grass hoppers feed on leaves leaving only veins on the leaves. Dusting of chlorpyrifos (1.5 %) or quinalphos dust @ 25 kg/ha in early stage may control both the insects. Sometimes the incidence of earhead eating caterpillar and aphids are also found which may be controlled by spraying crop with flubendiamide 39.35 SC (Fame) @ 100 ml or thiodicarb 75 WP @ 750 ml using 300 litres water per hectare.

HARVESTING AND THRESHING

The crop matures in about 120–135 days depending on the tract and the variety. Harvesting is generally done in two stages. The earheads are harvested with ordinary sickles and straw is cut close to the ground. Earheads are heaped for three to four days to cure and then threshed with hand or bullocks. At some places under rainfed conditions, the whole plant with earhead is cut, heaped and then threshed.

YIELD

With improved package and practices, it is possible to harvest 20–25 quintals of grain and 60 to 80 quintals of fodder/ha. The straw of mandua makes nutritious fodder. It can be conserved by putting up in well built stakes.

Proso Millet (Cheena)

(*Panicum miliaceum* L.)

Cheena or proso millet is an important minor millet grown in India. The crop is able to evade drought by its quick maturity. Being a short duration crop (60–90 days) with relatively low water requirement, this escapes drought period and therefore, offers better prospects for intensive cultivation in dryland areas. Under unirrigated conditions, cheena is generally grown during *Kharif* season but in areas where irrigation facilities are available, this is profitably grown as summer catch crop in high intensity rotations.

Proso millet has a high protein content (12.5%). It is rich in lysine an amino acid which is inadequate in most of the cereals. It contains lysine as high as 4.6% of protein. In addition to protein, it contains about 1.1% fat, 68.9% carbohydrates, 2.2% crude fibre and 3.4% ash. Grains of cheena are used in different ways as cooked grain, flour for making 'chapatis', parched grains, etc. It can be used in making *kheer*. Cheena makes a good poultry feed also. The straw is good fodder for cattle.

ORIGIN AND HISTORY

Proso millet probably originated in India. It spreads from India to other Proso millet growing parts of the world. It might have originated from *Panicum psibpodium* which is found in its wild state in Burma, India and Malaysia.

AREA AND DISTRIBUTION

Proso millet is one of the oldest grain crops and is grown in many parts of the world known by different names such as broom corn millet, hog millet, hershey millet, proso millet or common millet, etc. It is grown extensively in India, Japan, China, Egypt, Arabia and Western Europe.

In India cheena is largely grown in Madhya Pradesh, eastern Uttar Pradesh, Bihar, Tamil Nadu, Maharashtra, Andhra Pradesh and Karnataka.

BOTANICAL DESCRIPTION

It is an erect herbaceous annual which tillers profusely. Its plant grows up to a height of 45–100 cm. Stem is slender with distinctly swollen nodes. The roots are fibrous and shallow. The leaves are linear, slender and the leaf sheath encloses the entire internode. The inflorescence is a much branched panicle without bristles having spikelets at the tips of the branches. Usually, the last

or the fourth glume encloses a perfect flower which sets grain. The glume and palea are firmly attached to the grain. The seeds may be creamy white, yellow, red or black. Proso millet belongs to *Poaceae* family.

CLIMATIC REQUIREMENTS

Proso millet is a crop of warm climate. It is grown extensively in warm regions of the world. It is highly drought resistant and can be grown in areas where there is scanty rainfall. It can withstand water stagnation also to some extent. It is a hardy crop which completes its life cycle in a short span of time.



Fig. 8.1: Cheena plant

SOIL

Proso millet can be grown both in rich and poor soils, having variable texture, ranging between sandy loam to clays of black cotton soils. Coarse sands are not suited for Proso-millet cultivation. Well-drained loam or sandy loam soils free from Kankar and rich in organic matter are ideal for Proso millet cultivation.

VARIETIES

Not many high-yielding varieties of proso millet (Cheena) are yet available, however, some of the promising varieties with their specific features are furnished in Table 8.1.

CROPPING SYSTEMS

Proso millet fits well in low, as well as high intensity rotations:

Proso millet—wheat/barley/chickpea	] Low rainfall areas
Proso millet—toria/taramira	
Maize—potato—proso millet	] Irrigated areas
Maize—wheat—proso millet	
Maize—toria—wheat—proso millet	
Wheat—proso millet	

FIELD PREPARATION

Soon after harvesting of the previous crop, the field should be ploughed to expose the soil to sun and enable it to retain more moisture. With the onset of monsoon, the land should be harrowed two to three times and then finally

Table 8.1: Promising Proso millet (cheena) varieties suitable for growing in different states of India

Sl. No.	Name of variety	Institute where developed	Year of release	Maturity (days)	Average yield (Q/ha)	Area of adaptation	Special features
1	TNAU 202	TNAU, Coimbatore	2011	70-75	18-20	National	Profuse tillering and bold grains
2	TNAU 164	TNAU, Coimbatore	2009	70-75	18-20	National (entire India)	Non-lodging, tolerant to shootfly and rust
3	PRC 1	Ranichauri, GBPUA&T, Pantnagar	2008	70-75	10-12	Uttarakhand Hills	Resistant to leaf blight
4	TNAU 151	TNAU, Coimbatore	2008	72-75	18-20	National	Bold grains, resistant to shootfly
5	TNAU 145	TNAU, Coimbatore	2007	70-72	18-20	Tamil Nadu	High yielding, superior grain quality for value addition
6	CO (PV) 5 (TNAU 143)	TNAU, Coimbatore	2007	70-75	23-25	National (entire India)	High yield, profuse tillering, drought tolerant
7	Pratap Cheena-1 (PR-18)	MPUA&T, Udaipur	2006	65-70	15-17	National (entire India)	Early duration, dual purpose
8	GPUP 21	PC Unit, UAS, Bengaluru	2003	65-75	15-18	Karnataka, Tamil Nadu	High yield, moderately tolerant to shootfly
9	GPUP 8	UAS, Dharwad	2001	85-90	15-16	Karnataka	Resistant to brown spot
10	Bhawna	CSAUAT, Kanpur	1992	65-70	12-15	Uttar Pradesh	Early maturity
11	Co 4	TNAU, Coimbatore	1989	70-75	12-15	Tamil Nadu	Tolerant to shootfly and drought
12	Nagarjuna	ANGRAU, Hyderabad	1980	60-65	15-18	Andhra Pradesh	Early maturity
13	Sagar	ANGRAU, Hyderabad	1989	85-90	18-20	Andhra Pradesh	High seed yield
14	K 1	TNAU, Coimbatore	1982	65-70	9-10	Tamil Nadu	Stay green character

Source: ICAR—Indian Institute of Millets Research (IIMR), Hyderabad

levelled. When it is being grown during summer, one irrigation should be given prior to land preparation. As soon as the soil comes in the working conditions, the seedbed should be prepared by running harrow or desi plough thrice followed by planking. Cheena needs a firm and clean seedbed but does not respond to deep ploughing.

SEED AND SOWING

The importance of healthy and disease free seed hardly needs to be emphasised. Cheena is no exception. It is desirable that the seed be treated with organo-mercurial compounds like Thiram or Ceresan @ 2.5 g/kg of seed before sowing.

Time of Sowing

As a *Kharif* crop, Proso millet should be sown in the first fortnight of July with the onset of monsoon rains and as a summer crop it should be sown by the middle of April. During summer, it would be desirable to sow cheena as soon as the harvesting of the *Rabi* crop is over.

Seed Rate and Method of Sowing

Proso millet can be sown by broadcasting or by drilling seeds in furrows 3–4 cm deep. Row to row distance should be kept 25 cm and plant to plant 10 cm. Line sowing ensures better germination, cuts down seed requirement and facilitates intercultural operations compared to broadcast sowing. Depending upon the method of sowing, 8–12 kg seed is required for sowing one hectare of land.

MANURES AND FERTILISERS

Proso millet being a short duration crop, requires relatively less amount of nutrients compared to other cereals. To get a good crop, general fertiliser recommendations under irrigated condition are 40 kg nitrogen, 20 kg P_2O_5 and 20 kg K_2O /ha. Apply half of the nitrogen and whole amount of phosphorus and potash as a basal dose at the time of sowing. The remaining half of nitrogen should be applied at the time of first irrigation. Under rainfed condition, fertiliser dose is reduced to half of the irrigated crop.

If organic manure is available, it may be added to the soil about a month before sowing @ 5 to 10 tonnes/ha.

WATER MANAGEMENT

Proso millet sown during *Kharif* season, generally does not require any irrigation. However, at tillering stage, if dry spell prevails for longer period, then one irrigation must be given to boost yields. Summer crop, however, would require two to four irrigations depending upon soil type and climatic conditions. Give first irrigation 25–30 days after sowing and second irrigation

about 40–45 days after sowing. Due to shallow root system of Proso millet, heavy irrigation is not advisable.

WEED CONTROL

For getting high-yield and minimising loss of soil moisture and nutrients, the field should be kept weed-free up to 35 days' stage. Two weedings at an interval of 15–20 days would help control it. Weedings may be done with hand hoe or wheel hoe.

DISEASES

Head smut

Head smut (*Sphacelotheca destruens*) is a common disease of Proso millet. The affected panicles become elongated and thickened. The smut masses rupture before harvest. This is a seed-borne disease and can be controlled by treating seeds with Vitavax + Thiram @ 3 g/kg seed or hot water treatment (soaking seeds in hot water at 55°C for 7–12 minutes).

Control Measures

- Grow healthy seed free from disease.

Grain Smut

The disease is caused by *Aphacelotheca sorghi* and also known as covered kernel smut. Most of the grains are transformed into white grayish sacs (smut sori). The sori are slightly pointed to oval and filled with black powder.

Control Measures

- Grow healthy seed free from disease.
- Collection and burning of diseased ears on appearance and crop rotation for 2–3 years.

Leaf Spot

Disease is caused by *Helminthosporium panici-miliacei* and transmitted through seed. Seed infection causes seed rotting, coleoptile spot and seedling blight.

Control Measures

- Grow resistant varieties such as RAUM 7.

INSECT PESTS

Among insects, shoofly is important for this crop. This insect damages the crop in the seedling stage. Apply 25 kg/ha quinalphos (1.5%) dust in the soil at time of field preparation. This fly can also be controlled by spraying the crop with cypermethrin 10 EC @ 550 ml or diflubenzuron 25 WP @ 1150 g or imidacloprid 48 FS @ 1200 ml by using 700 litres of water per hectare.

HARVESTING AND THRESHING

Proso millet is ready for harvest after 65–75 days of sowing in most of the varieties. Harvest the crop when it is about to mature. The seeds in the tip of upper heads ripe and shatter before the lower seeds and later panicles get mature. Therefore, the crop should be harvested when about two-thirds of seeds are ripe. Crop is threshed with hand or bullocks.

YIELD

With improved package of practices it is possible to harvest 20–25 quintals of grain and 50–60 quintals of straw/ha.

Barnyard Millet (Sawan)

(*Echinochloa frumentacea* L.)

Sawan or barnyard millet is a grain crop of lesser importance. It is very drought resistant but is also capable of withstanding water logging conditions. It is generally grown as a rainfed crop. Sawan grains are consumed just like rice. They are also used in making rice pudding (kheer). Sawan grain contains 6.2% protein, 9.8% crude fibre, 65.5% carbohydrates, 4.4% ash. The digestibility of protein is 40%. The grain is eaten mostly by the poor classes, but sometimes it is brewed for beer. It is also used as feed for cage birds. The straw makes good fodder for cattle. Its green fodder is very much relished by cattle.

ORIGIN AND HISTORY

There is a mention of barnyard millet in ancient literature of India. It has been cultivated in China for more than 2000 years. Some of the investigators think that sawan probably originated somewhere in central Asia. It spreads from central Asia to Europe and America.

AREA AND DISTRIBUTION

Sawan or barnyard millet is grown in India, China, Japan, Malaysia and East Indies. In China and Japan it is said to be grown as a substitute crop when the rice crop fails. It is also grown to some extent in Africa and United States of America.

In India it is grown in Madhya Pradesh, Uttar Pradesh, Uttarakhand, Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Bihar.

BOTANICAL DESCRIPTION

It is an herbaceous annual which tillers sparsely. Plant grows up to a height of 60 to 120 cm. The roots are fibrous and shallow. Stem is slender. Leaves are flat, glabrous or slightly hairy without ligule. The inflorescence is a panicle with densely crowded unawned spikelets. Spikelets are densely packed in three to five rows. The spikelets are subsided by two glumes within which there are two florets. Colour of the glume varies from white to red. The caryopsis remains enclosed in the lemma and palea. Colour of the grain is generally yellow or white. Barnyard millet belongs to *Poaceae* family.

CLIMATIC REQUIREMENTS

Barnyard millet (Sawan) is a drought tolerant crop and hence is grown as a rainfed crop. It can be grown successfully under partially water logged conditions. It is grown from sea level to an altitude of 2000 m on the Himalayan slopes. Warm and moderately humid climate is good for raising sawan crop. It is a hardy crop and is able to withstand adverse conditions of weather better than other cereals.

SOIL

Barnyard millet (Sawan) is generally cultivated in soils of marginal fertility. It can be grown in partially water logged soils such as low lands on the banks of rivers, etc. But it thrives best on sandy loam to loam soil having sufficient amount of organic matter. Gravely and stony soils with poor fertility are not suitable for raising sawan crop.

VARIETIES

Promising varieties of Barnyard millet are given in Table 9.1.

Description of some of the improved varieties of barnyard millet (sawan) is given as follows:

K 1: This variety matures in 100–115 days. It is suitable for growing in Tamil Nadu state. It yields about 10 quintals of grain/ha.

T 46: It is a very popular variety for Uttar Pradesh. It yields about 10–12 quintals of grain/ha.

VL 1: This variety is specially suitable for growing in hilly areas of Uttarakhand. It yields about 12–15 quintals of grain/ha under favourable conditions.

IP 149: This variety takes about 80 to 90 days to mature. Plant height is 145 cm. Length of the earheads is 26 to 29 cm. Grains are of light brown colour. It yields about 12–13 quintals of grain/ha.

UPT 8: This variety matures in 74–80 days. Plants are erect with leaves of light green colour. Plant height is 126–130 cm. Grains are of light brown colour. It yields about 12 quintals of grain/ha.

Kanchan: This variety matures in 85–90 days. It is a selection from local germplasm. It is suitable to grow in hills of Uttarakhand. Its average yield is 15–18 quintals/ha.



Fig. 9.1: Plant of sawan

Table 9.1: Promising barnyard millet (sawan) varieties suitable for growing in different states of India

State	Recommended varieties
Andhra Pradesh	DHBM 93-3, VL Madira 181
Bihar	RAU 11 (Sushrutha), VL Madira 181
Jharkhand	VL Madira 181, VL 172
Gujarat	DHBM 93-3, VL Madira 172
Karnataka	Sushrutha, VL Madira 172, VL Madira 181
Madhya Pradesh	VL Madira 181, VL Madira 172, DHBM 93-3
Tamil Nadu	VL Madira 181, DHBM 93-3
Uttar Pradesh	Kanchan, DHBM 93-3
Uttarakhand	VL Madira 172, VL Madira 181, PRJ 1

IPM 97: This variety takes about 83 to 88 days to mature. Plant height is 140–150 cm. Length of the earheads is 12–14 cm. The plants are usually erect. It yields about 10 quintals of grain/ha. Grains are of light brown colour.

IPM 100: It is an early maturing variety which takes only 65–67 days to mature. Plant height is 130–140 cm. Grains are of light brown colour. It yields about 10–12 quintals of grain/ha.

IPM 148: This variety matures in 77–86 days. Plant height is 150–162 cm. Grains are of light brown colour. It yields about 11–12 quintals of grain/ha.

IPM 151: It takes about 80–88 days to mature. Plant height is 135–162 cm. Length of the earhead is 14–17 cm. Plants are erect with narrow leaves. It yields about 12–13 quintals of grain/ha.

In addition to above, VL Madira 21, VL Madira 29, VL Madira 181, VL Madira 172, CO (KV) 2 and Kanchan are new promising varieties.

CROPPING SYSTEMS

It is raised as a pure crop in rotation with chickpea, pea, linseed, barley, etc. The common cropping systems are given below:

Barnyard millet—chickpea

Barnyard millet—field pea

Barnyard millet—linseed

Barnyard millet—barley

It is also grown mixed with cotton, pigeon pea or other short duration pulses.

FIELD PREPARATION

Since it is cultivated in very light and marginal soils, the land is given only a limited preparatory cultivation. Two ploughings with local plough or harrowing followed by planking are sufficient to prepare the seedbed for sawan.

SEED AND SOWING

Barnyard millet (sawan) can be sown in the first fortnight of July with the onset of monsoon rains. The seed is broadcast or drilled in furrows 3–4 cm deep @ 8–10 kg/ha. Transplanting is also done in some places in Maharashtra. It is always better to sow it in rows 25 cm apart. In flood affected areas, it is sown with the first showers of rain by broadcast method and harvested before the flood may come.

MANURES AND FERTILISERS

Farm yard manure or compost @ 5 to 10 tonnes/ha should be added for boosting the yield. It can be supplemented with 40 kg nitrogen, 20 kg P_2O_5 and 20 kg K_2O /ha. All the fertiliser should be added in the soil at the time of sowing. If irrigation facilities are available, half of the nitrogen should be top-dressed in standing crop after 25–30 days of sowing.

WATER MANAGEMENT

Generally barnyard millet (sawan) does not require any irrigation. However, if dry spell prevails for a long period, then one irrigation must be given at the time of panicle initiation stage. It is always better if excess water of heavy rains is drained out of the field.

WEED CONTROL

The field should be kept weed free up to 25–30 days after sowing. Two weedings are sufficient to control the weeds in barnyard millet field. Weedings may be done with hand hoe or wheel hoe in line sown crop.

DISEASES

Downy Mildew

It is caused by a fungus. Sometimes it may cause severe damage to the crop plants. In the beginning the light yellow bands are seen on the leaves which in due course of time become white. Later on, leaves start drying and in case of severe infection earheads become chaffy. Remove the infected plants and destroy them. Use seed from healthy plants only.

Spray 0.2% Mancozeb 75 WP or Metalaxyl + Mancozeb @ 3 g/L water in standing crop.

Head Smut

It is also caused by a fungus *Ustilage crussgalli*. The affected panicles are full of black masses instead of grains. This is a seed-borne disease and can be controlled by treating the seed with Thiram or Ceresan @ 2.5 g/kg of seed or hot water

treatment (soaking seed in hot water at 55°C for 7–12 minutes). Rouging of infected plants from the field is also helpful in reducing the spread of disease.

Rust

It is caused by a fungus. Black spots are seen in lines on leaves. It causes considerable reduction in grain yield. Spray of Mancozeb 75 WP @ 2 kg in 1000 L of water/ha or Propiconazole (Tilt) 25 EC @ 1 L/ha may check the spread of this disease.

Leaf Spot or Blight

The disease is caused by *Helminthosporium crugalli* and appears as isolated, dark brown, scattered and spindle-shaped spots on flag leaves. Afterwards, several such spots coalesce and cover the entire leaf, which becomes grey and dried up. The spots are dark brown to grey in colour and are surrounded by yellow halo. Just after the appearance of the lesions, dark points are visible in the centre.

Control Measures

- Field sanitation free from plant disease debris.
- Grow resistant genotypes.

INSECT PESTS

Termites and stem borers are important pests of this crop. Termites can be controlled by treating the seed at the rate of 1 g Cruiser 70 WS (thiamethoxam) or 2 ml Neonix 20 FS (imidacloprid+hexaconazole) per kg seed. It can also be controlled by dusting chlorpyrifos 1.5% dust @ 25 kg/ha. It should be mixed properly in the soil. Stem borer can be controlled by spraying 75 ml chlor-antraniliprole 18.5 SC (Coragen) using 300 litres water.

HARVESTING AND THRESHING

The crop should be harvested when it is ripe. It is cut from the ground level with the help of sickles and stacked in the field for about a week before threshing. Threshing is done by trampling under the feet of bullocks.

YIELD

With improved package of practices, it is possible to obtain 12–15 quintals of grain and 20–25 quintals of straw/ha.

Kodo

(*Paspalum scrobiculatum* L.)

Kodo millet is a highly drought resistant crop. It is the coarsest of all food grains. The grain is covered with a horny seed coat which should be removed before cooking. Immature and molded grains are supposed to be poisonous. Kodo grain is easily preserved and proves as a good famine reserve. The grain is recommended as a substitute for rice to patients suffering from diabetes disease. The grain contains 8.3% protein, 1.4% fat, 65.6% carbohydrates and 2.9% ash. Straw is very poor in quality and harmful to horses.

ORIGIN AND HISTORY

Kodo millet is a very old crop. There is a mention of kodo in ancient literature of India. Some of the investigators think that kodo probably originated in southeast Asia. Forage species of kodo '*Paspalum dilatatum*' is grown in America, Australia and South Africa.

AREA AND DISTRIBUTION

Kodo is grown mostly in Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu and Uttar Pradesh. In Uttar Pradesh it is grown mostly in Gorakhpur, Basti, Gonda, Deoria, Mirzapur and Sitapur districts.

BOTANICAL DESCRIPTION

Kodo is an erect annual, growing to a height of 45–90 cm or more. It is quite distinct from other millets due to purple pigmentation in leaves. The crop has a characteristic violet look. The plant tillers moderately. The leaves are stiff, narrow and thick with membranous and hairy ligule. The inflorescences is a raceme with the spikelets arranged on one side of a flattened rachis. The spikelets are one flowered. The crop is generally self-pollinated. The caryopsis is tightly enclosed by the hard lemma and palea which form the husks of the grain. Kodo belongs to *Poaceae* family.

CLIMATIC REQUIREMENTS

Kodo makes a rapid growth in warm and dry climate. It is highly drought tolerant and, therefore, can be grown in areas where rainfall is scanty and erratic. It grows well in areas receiving only 40–50 cm annual rainfall.

SOIL

Kodo is grown from gravelly and stony upland poor soils to loam soils. In spite of adverse conditions the crop can struggle on even poor soils and may yield some quantity of grain and straw. But it thrives best on sandy loam to loam soils. Soil should be well-drained.

VARIETIES

There are some promising varieties of kodo suitable for growing in different states. These are furnished in Table 10.1.

CROPPING SYSTEMS

Kodo can be grown as a pure crop or mixed with Pigeonpea (arhar), sesamum and sun hemp. Sometimes kodo is mixed with sorghum and black-gram. It is generally grown in rotation with mustard, linseed and chickpea, barley, etc. The common cropping systems are as follows:

Kodo-linseed

Kodo-chickpea

Kodo-mustard/taramira

Kodo-barley

FIELD PREPARATION

Before the onset of monsoon the field should be ploughed to get good tilth and enable it to retain moisture. With the onset of monsoon field should be harrowed or ploughed with local plough two to three times followed by planking. Field should be levelled.

SEED AND SOWING

Sowing time for kodo is between June 15 and July 15 in northern India. In south, it is mostly grown as rainfed crop from September to December. It is beneficial to sow kodo in lines 3–4 cm deep. Line to line distance should be 40–45 cm and plant to plant distance 8–10 cm. Ten to 15 kg seed is sufficient for sowing one hectare. It may be sown by broadcast method but it is not a good practice.

MANURES AND FERTILISERS

Addition of organic manures is always beneficial since it helps to improve the water retention capacity of soil in addition to providing essential nutrients to the crop plants. The crop should be manured with 5 to 10 tonnes of farm yard manure/ha. Apply 40 kg nitrogen, 20 kg P_2O_5 and 20 kg K_2O /ha in the form of chemical fertilisers. All the fertilisers may be applied at the time of sowing in furrows.

Table 10.1: Recommended varieties of kodo millet for cultivation in different states of India

Sl. No.	Name of variety	Institute where developed	Year of release	Maturity (days)	Average yield (Q/ha)	Area of adaptation	Special features
1	Indira Kodo 1	Jagdarpur IGKVV	2012	100–105	22–25	Chhattisgarh	Highly responsive to fertilizers, suitable for late sowing
2	TNAU-86	TNAU, Coimbatore	2012	95–110	27–30	National	Early duration, non-lodging, milling recovery (52–53%)
3	DPS 9-1	Dindori, JNKVV, Jabalpur	2011	105–110	27–30	National	Tolerant to shootfly
4	JK 98	Rewa, JNKVV, Jabalpur	2010	100–105	25–30	National	Resistant to shootfly and moderately resistant to head smut
5	JK 106	Rewa, JNKVV, Jabalpur	2009	100–105	19–20	MP state	Resistant to head smut and shootfly
6	JK 65	Rewa, JNKVV, Jabalpur	2009	105–110	23–25	National	Resistant to shootfly and moderately resistant to head smut
7	JK 13	Rewa, JNKVV, Jabalpur	2007	95–100	22–23	National	Resistant to head smut and shootfly
8	KK 2	CSAUA&T, Kanpur	2002	82–85	20–23	Uttar Pradesh	Resistant to drought and lodging and suitable for saline condition
9	Jawaharkodo 48 (JK 48)	JNKVV, Jabalpur	2001	95–100	26–27	Andhra Pradesh, Gujarat, Madhya Pradesh, Chhattisgarh, Karnataka	Resistant to head smut and tolerant to drought, high grain yield
10	Jawaharkodo 155 (RBK 155)	JNKVV, Jabalpur	2000	105–110	20–22	Madhya Pradesh, Karnataka	Resistant to head smut, shootfly

Source: ICAR—Indian Institute of Millets Research (IIMR), Hyderabad

WATER MANAGEMENT

Kodo sown in *Kharif* season generally does not require any irrigation. It is mostly grown as a rainfed crop. If irrigation facilities exist, apply one or two irrigations at the times when rains stop for a long spell. Drainout the excess rain water from the field during heavy and continuous rains.

WEED CONTROL

It is essential to control weeds in the initial stages of plant growth. Field should remain weed-free up to 35–40 days of sowing. Generally two weedings at an interval of 15 days are sufficient. Weeding may be done with hand hoe or wheel hoe in line sown crop.

DISEASES

Ergot or Sugary Disease

The disease is caused by *Claviceps pastali* and manifests itself at the time of panicle emergence. Generally individual spikelets are affected but sometimes majority of the spikelets in the panicle may also be affected. The most peculiar external sign of the disease is the exudation of perly drops of honeydew oozing out of the infected spikelets. This indicates the 'sugary or honeydew' symptom. The droplets are soon hardened into reddish brown crusts. As the panicle matures, dark grey sclerotia or ergot replace the kernel which is the most conspicuous symptom of the disease.

Control Measures

Removal and destruction of infected panicles and eradication of the alternate hosts can minimize the primary inoculum.

Head Smut

The disease manifests itself at the time of flowering. Infected plants remain stunted and almost all the panicles in the infected plants are transformed into a long sorus. In early stage, a cream-coloured thin membrane covers the sorus.

Control Measures

- Seed treatment with Vitavax + Thiram @ 3 g/kg of seed.
- Use of resistant genotypes GPLM 78, 96, 176, 322, 364, 621, 641, 679 and 720 can also help in minimizing the damage.

Rust

The disease is caused by *Puccinia substriata*. The erumpent, oval brown uredia are formed on the upper surface of the leaf blade and on the leaf sheath. The brown-coloured telia are formed on the under surface of leaf blade and on the leaf sheath during December–February in cold-humid conditions. They remain covered by the epidermis for a long time. Under sheltered conditions, uredia

are present throughout the year on grass hosts and from where they disseminate to the main cultivated crop.

Control Measures

Eradication of grass hosts is partly useful in reducing the primary inoculum of the disease.

INSECT PESTS

White ants and stem borers are major insect pest of kodo crop. White ants may be controlled by applying by imidacloprid 48 FS @ 1200 ml or imidacloprid 17.8 SL @ 350 ml. Stem borer can be controlled by spraying 75 ml chlor-antraniliprole 18.5 SC (Coragen) using 300 litres water.

HARVESTING AND THRESHING

The crop becomes ready for harvest in the month of September or October in northern India. The plants are cut close to the ground, bundled and stacked for a week and then threshed by trampling under the feet of bullocks.

YIELD

With improved package of practices one can obtain 15–18 quintals of grain and 30–40 quintals of straw/ha. For proper storage moisture in grain should not be more than 10–12%.

Kakun (Foxtail millet)

(*Setaria italica* (L.) Beauv.)

Kakun or foxtail millet is also known as Italian millet, and German millet. It is generally grown as a rainfed crop in India. The grains are cooked like rice and then utilised. In some areas the grains are ground to flour and used in the form of 'chapatis'. Kakun grain contains 12.3% protein, 4.7% fat, 60.6% carbohydrates and 3.2% ash. The grains are fed to cage birds. The straw is thin stemmed and is liked by cattle. It is not good for horses. In China, Italian millet is next to rice and wheat in importance. It provides approximately 15–17% of the total food consumed in China.

ORIGIN AND HISTORY

Kakun (foxtail millet) is a very old crop. Seeds of this millet have been found in early remains such as those of the Swiss lake-dwellers of the stone age. It was cultivated in China as early as 2700 BC. Vavilov (1935) considered China as its place of origin. Werth considers China or Central Asia as its place of origin. According to him kakun spreads to India and other European countries from there.

AREA AND DISTRIBUTION

Foxtail millet (Kakun) is cultivated in India, China, Eastern Europe, Southern parts of Russia and to some extent in African and American countries. In India it is cultivated in Karnataka, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh and Uttarakhand.

BOTANICAL DESCRIPTION

Kakun or foxtail millet is an annual with slender and erect stems. It grows to a height of 90–150 cm and bends down a great deal with weight of earheads. Leaves are narrow, flat and about 30–45 cm long. The inflorescence is dense, cylindrical and bristly panicle 8–32 cm long, often arching towards the tip. In some of the varieties they are drooping, loose and open. There are one to four bristles at the base of each spikelet, these give the foxtail look to the panicle. The seeds are small, convex and enclosed in the hard inner glume and its palea. The hulls are of various colours, creamy white to orange red and even purple. Kakun belongs to *Poaceae* family.

CLIMATIC REQUIREMENTS

Foxtail millet (Kakun) is cultivated in tropical as well as temperate regions. The crop can be grown even at an altitude of 2000 m. It requires moderate temperature throughout its life cycle. The crop can be grown successfully in areas receiving 50–75 cm annual rainfall. Although its water requirement is low, the plant has no capacity to recover after a long spell of drought.

SOIL

Foxtail millet (Kakun) requires a fairly fertile soil for good yields, although it can grow in poor soils. Light soils including red loams, alluvials, and black cotton soils are all suitable for its cultivation but it thrives best on rich, well-drained loam soils.

VARIETIES

There are several improved varieties of Foxtail millet (Kakun) suitable for growing in different states are given in Table 11.1.



Fig. 11.1: Italian millet (Kakun)

CROPPING SYSTEMS

Generally, it is sown as a mixed crop with cotton, maize, Pigeon pea and blackgram, but sometimes it is raised as a pure crop. When it is sown as a pure crop the following cropping systems are followed:

- Kakun-linseed
- Kakun-chickpea
- Kakun-barley
- Kakun-field pea.

FIELD PREPARATION

Kakun does not require much field preparation. Before the onset of monsoon, the field should be ploughed once with mould board plough. With the onset of monsoon, the field should be harrowed or ploughed with a local plough twice in northern India or with blade harrow in south India. Planking should be done for making the field smooth and well-levelled.

SEED AND SOWING

An early crop of kakun is sown in May, main crop in June–July while the late in August. In areas of assured water supply, summer crop is sown in February–March. Optimum time of sowing of Kakun in Tamil Nadu is August–September for rainfed crop and June–July for irrigated one. In Madhya Pradesh it is grown as a rainfed crop and, therefore, sowing at the onset of monsoon is preferred.

Table 11.1: Recommended varieties of Kakun (Foxtail millet) for cultivation in different States of India

Sl. No.	Name of variety	Institute where developed	Year of release	Maturity (days)	Average yield (Q/ha)	Area of adaptation	Special features
1	Suryanandi (SiA 3088)	RARS, Nandyal, ANRAU	2012	70-75	20-25	All foxtail millet growing areas of the country	Non-lodging, early duration, suitable for double cropping
2	SiA 3156	RARS, Nandyal, ANRAU	2012	85-90	20-25	Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Tamil Nadu and Uttarakhand	Highly responsive to nitrogenous fertilizers
3	SiA 3085	RARS, Nandyal, ANRAU	2011	80-85	20-30	All foxtail millet growing areas of the country	Resistant to blast and downey mildew
4	HMT 100-1	ARS, Nandyal, ANRAU	2008	90-95	20-25	Karnataka	High tillering, suitable for early and late sowing
5	Co 7 (TNAU 196)	RARS, Nandyal, ANRAU	2005	85-90	18-19	Tamil Nadu	High protein (13.62 to 14.0%) and fodder yield (3.7 to 4.0 t/ha)
6	TNAU 196	RARS, Nandyal, ANRAU	2005	85-90	18-20	Tamil Nadu	Resistant to rust
7	Prathapkangni 1 (SR-51)	RARS, Nandyal, ANRAU	2003	65-70	18-20	Rajasthan	Extra early maturity, nutritionally superior
8	Sri Lakshmi	RARS, Nandyal, ANRAU	2002	80-85	20-23	Andhra Pradesh	High seed yield
9	Meera (SR-16)	RARS, Nandyal, ANRAU	2001	75-80	15-17	Rajasthan	Stay green character, resistant to downey mildew
10	PRK 1	RARS, Nandyal, ANRAU	2000	75-80	19-20	Uttar Pradesh	Early maturity
11	PS 4	RARS, Nandyal, ANRAU	1998	80-85	18-20	All States	Wider adaptability
12	Gavari (SR-11)	RARS, Nandyal, ANRAU	1994	75-80	15-16	Rajasthan	
13	TNAU 43	RARS, Nandyal, ANRAU	1994	80-85	15-16	Tamil Nadu	High fodder yield

Source: ICAR—Indian Institute of Millets Research (IIMR), Hyderabad

The crop is generally sown in rows at 25–30 cm distance. Seeds should be sown in furrows 2–3 cm deep. Eight to ten kg seed is sufficient for sowing of one hectare of land. Kakun is sometimes sown by broadcast but it is not a good practice. Seed should be treated with Thiram @ 2.5 g/kg of seed.

MANURES AND FERTILISERS

The crop is usually manured with 5 to 10 tonnes of farm yard manure/ha. General fertiliser recommendations to get a good crop are 40 kg nitrogen, 20 kg P_2O_5 and 20 kg K_2O /ha. All the fertilisers should be applied as a basal dose at the time of sowing. If irrigation is available, apply only half of the nitrogen and full amount of phosphorus and potash at the time of sowing and remaining half quantity of nitrogen at the time of first irrigation.

WATER MANAGEMENT

Kakun sown during *Kharif* season does not require any irrigation. However, if dry spell prevails for longer period, then one or two irrigations must be given to boost yields. Summer crop, however, would require two to five irrigations depending upon soil type and climatic conditions. During rainy season, drainage is also essential. Remove excess rain water from the field as Kakun does not withstand water logged conditions.

WEED CONTROL

It is desirable to control the weeds in the initial stage of plant growth. Two to three weedings with hand hoe are sufficient to keep the weeds in control.

DISEASES

Blast

This disease is caused by *Pyricularia setariae*. On leaves symptoms develop as small pin-head water soaked yellowish dot that turns circular or oval-shaped within 2–3 days with greyish centre surrounded by dark brown margin. The small and scattered spots measure 2 to 5 mm in diameter. The spots coalesce and in severe form the leaves wither and dry up. When the node is affected, it turns black and breaks at the nodal junction.

Control Measures

- Grow resistant genotypes/varieties SR 118, SR 102, ISc 709, 701, 703, 710, 201, JNSc 33, 56, RS 179, ST 5307, SiA 3085.
- Destroy plant disease debris.

Smut

The disease is caused by *Ustilago crameri*. Low temperature and high relative humidity are favourable for rapid development and spread of the disease. The fungus affects most of the grains in an ear-producing sori in the flowers and basal parts of the palea but sometimes terminal portion of the spike may escape.

The sori are pale greyish in colour. When the crop matures, the sori ruptures and produces dark powdery mass of spores.

Control Measures

- Grow healthy seeds free from disease.
- Rough out the infected plants from field.

Downey Mildew or Green Ear

The disease is caused by *Sclerospora graminicola*. The first symptom of the disease is chlorosis of the seedling leaves. The terminal spindle fails to unroll, becomes chlorotic which later turns brown and gets shredded. When the infection is mild, the plant may develop ears, but the floral parts are proliferated into green leafy structures showing 'green ear' symptom. When the infection is secondary, occurring late in the season, only chlorotic patches are seen on the upper leaf surface, with the downy fungus growth on the corresponding lower surface.

Control Measures

Collection and removal of infected plant debris helps in reducing the inoculum in the field.

INSECT PESTS

There is not much problem of insect pests in Kakun. Some of the pests which attack kodo may also attack Kakun crop. Control measures are similar to kodo crop.

HARVESTING AND THRESHING

The crop flowers in 50–60 days and matures in 80–100 days. The crop is harvested when the earheads are dry, either by cutting the whole plant by sickle or the ears separately. After drying for few days, threshing is done with a stone roller or by trampling under the feet of bullocks.

YIELD

With improved package of practices one can obtain 15–18 quintals of grain and 20–40 quintals of straw/ha.