Bulb Vegetables Production Technology

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Bulb vegetables constitute an important group of horticultural crops that are valued for their nutritional, medicinal, culinary, and economic value. Basic bulb vegetables such as onions, garlic, shallots, and leeks are widely cultivated underground for food, for processing and preservation, and for various uses in the food and pharmaceutical industries. Production techniques for bulb vegetables include variety selection, climate and soil conditions, land preparation, propagation methods, nutrient management, irrigation, weed management, and integrated pest and disease management. Modern production approaches such as precision agriculture, drip irrigation, fertilization, mulching, improved planting techniques, and integrated nutrient management play an important role in improving productivity, resource use efficiency, and crop quality. Special emphasis is placed on bulb development, maturity assessment, harvesting techniques, curing, grading, packaging, storage, and post-harvest management to minimize losses and extend shelf life. Furthermore, the adoption of improved cultivars, climate-resilient production practices, and sustainable crop management strategies can help address challenges associated with climate variability, soil degradation, and fluctuating market demands. Understanding the scientific principles and practical aspects of bulb vegetable production techniques is essential to achieve higher yields, improve bulb quality, increase farmer incomes, and ensure a sustainable supply of these commercially important crops. This chapter provides students, researchers, agricultural professionals, and growers with a comprehensive overview of production practices, technological advances, and future prospects for bulb vegetable cultivation.

Keywords: *Bulb vegetables, Onion, garlic, Shallot, leek, Production technology, Cultivation practices, Nutrient management, Irrigation management, Integrated pest and disease management, Bulb development, Harvesting, Post-harvest management*

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Introduction

Allium includes various vegetables besides onion and garlic *viz.* leek; scallion; shallot; wild garlic; great headed garlic; chives etc. Throughout the world, it is one of the largest genera having more than 700 species. Haller in 1745 listed 24 species of the genus in the first published monograph of *Allium* that has eventually being increased to 750 species. More than 900 species including 15 subgenera and 57 sections involvs in *Allium* genus, presently, making it one of the largest monocotyledon genera throught out the globe. Its region of diversity extends from the Mediterranean region to Central Asia. *Allium* includes onion and shallot (*Allium cepa*); garlic (*A. sativum*); leek and elephant garlic (*A. ampeloprasum*); Japanese bunching onion (*A. fistulosum*); chives (*A. schoenoprasum*); garlic chives (*A. tuberosum*). Its many species are also grown as ornamentals like *A. giganteum*; *A. christophii*; *A. karataviense*; *A. aflatunense*; *A. caeruleum*; the nodding onion (*A. cernuum*); the yellow flowered *A. moly* and the interspecific cultivar Globe master. A few *Allium* species are also noxious weeds in some parts of the world viz. *A. vineale* and *A. triquetrum* (Kumar et al. 2020).

Origin, Distribution and Season

Alliums are among the cultivated plant species under family Alliaceae grown for food, medicines and religious purpose. It is mostly strong flavoured because of sulphur containing compounds responsible for distinctive smell and pungency. Onion and garlic have bulbs and cloves, respectively as an underground storage organ, which are also used for vegetative propagation. *Alliums* are native to Asia and the Middle East and have been cultivated for over five thousand years. Its origin place is unknown; but it occupied a vast area in Western Asia during very early epoch, extending, perhaps from Mediterranean basis, Palestine to India and central Asia. So, its centre of origin is remains debatable, the middle Asiatic countries in the region of Iran and Pakistan are considered to be the primary centre of onion origin. The near east Asiatic and Mediterranean regions are considered to be secondary centre of origin. The next most important centre is located in western North America. Vavilov (1926) proposed southwest Asian gene centre as primary centre of domestication and variability of onion. Based on ecotypes and wild forms, Vavilov and Burkinich (1929) confirmed that Afghanistan and adjacent countries are the genetic centre of origin of the cultivated forms of onion and garlic (Vaddoria and Kulkarni, 2018). Onion and garlic are being cultivated in India and China in large areas. In India, onion is cultivated in three seasons i.e. *kharif,* late *kharif* and *rabi.* Main season is *rabi* which acounts about 50% of production, whereas, about 20% is from *kharif* and 30% from late *kharif.*

During 2024-25, India accounting final total 218 million tonnes production of vegetables annually from 11.80 million hectares, while, 30767 ‘000’ tonnes production of onion from 1968 ‘000’ hectares (Anon. 2025-26). In terms of total vegetable production share of the states, West Bengal is the leading (29337 ‘000’ t from 1570.81‘000’ ha), while Madhya Pradesh ranks second (24191 ‘000’ t from 1298‘000’ ha) followed by Gujarat (18013 ‘000’ t from 881‘000’ ha) and Maharashtra (16556 ‘000’ t from 1262‘000’ ha) during 2024-25 (Anon. 2025-26). Maharashtra is leading producer of onion (13046‘000’ t from 989‘000’ ha) followed by Madhya Pradesh (4699‘000’ t from 225‘000’ ha); Gujarat (2607‘000’ t from 118‘000’ ha). India’s over 49% area and 44.07% production alone come from Maharashtra (https://apeda.gov.in). Nearly 68-80% onion is exported from Maharashtra (https://timesofindia.indiatimes.com). Stored onions during May to November used for domestic use and export market. *Kharif* onion produce is available in the market during November to December, whereas late *kharif* crop produce during January to March from Maharashtra but, there is critical shortage in arrivals of onion in the market during November to January. The productivity of late *kharif* and *rabi* onion is around 25 t ha^{-1}, whereas of *kharif* is 8-10 t ha^{-1}. Cloudy weather and constant

drizzling during *kharif* season are fourable conditions for diseases infections like anthracnose and bulb rotting leading to low productivity. In *rabi* season, high incidence of thrips besides yield loss also aggravates the problem of purple blotch and *Stemphylium* blight, which again pulls down the productivity. During 2024-25, India accounting 30767 '000' tonnes production of onion from 1968 '000' hectares (Anon. 2025-26). Maharashtra is leading producer of onion (13046'000' t from 989'000' ha) followed by Madhya Pradesh (4699'000' t from 225'000' ha); Gujarat (2607'000' t from 118'000' ha). The important principle viz. *allicin, ajoene, allixin thiosulfinates* and *sulphites* etc (Anon. 2025-26). present in onion, makes it potential herb. These compounds help fighting *cancer*; *high blood cholesterol* and *sugar*; *liver problems* and *intestinal* problems.

Classification of *Allium cepa*

Commonly cultivated *Alliums* are common onion [*A. cepa* var. *cepa* L. (2n=16)]; Shallot [*A. cepa* var. *aggeregatum* G. Don. or *A. ascalonicum* (2n=16)]; Welsh onion [*A. fistulosum* L. (2n=16)]; Chinese chives [*A. tuberosum* Rotti. Ex Spreng (2n=32)]; Garlic [*A. sativum* L. (2n=16)]; Leek [*A. ampeloprasum* var. *porrum* (L.) J. Gay (2n=32)] and Chives [*A. schoenoprasum* L. (2n=16, 24, 32)] (Mahajan et al. 2020).

Allium cepa

Within thisgenus, onion (*Allium cepa*; Family: Alliaceae), a diploid species with 16 chromosomes (2n= 2x= 16), is the most extensively cultivated and consumed vegetable crop (Ochar and Kim 2023). The onion is a biennial herbaceous and is typically grown for bulbs as annuals. This group is economically most important *Allium* crop. It includes open pollinated traditional and modern cultivars, hybrids and local races, cultivated in the world. The bulbs are large and normally single and plants reproduce from seeds or from seed-grown sets. The majority of cultivars grown for dry bulbs belong to this group. Maximum diversity exists in North India; Pakistan; former Soviet Union; Europe; Middle East and in Mediterranean area (Vaddoria and Kulkarni, 2018). It is consumed in various forms and used in various cuisines. Onion is characterized by its distinct flavour and pungency which are due to various sulphur compounds. The chemical composition varies from variety to variety and with season of production and storage life. Dehydrated onion in the form of rings; powder; kibbles; etc. is in great demand. The processing industries require white onion varieties with high TSS. Various other products, viz. onion oil; onion juice; onion salt or onion pickles, can be prepared.

***A. ascalonicum* (Shallot)**

It is perennial, usually has two-three cloves and occasionally as many as ten. Shallot bulbs grow in clusters and have a distinctive tapered shape that sets them apart from other members of the alliaceae family. Most often these are of copper brown colour or reddish. Their flavour, sometimes described as a blend of sweet onion and garlic. Plant grows up to about 30-60 cm. It is propagated only by cloves or bullets as no seeds are produced. Its morphology resembles both with the onion and garlic. The bulblets resembles garlic and its texture and colour with onion. Mostely bulbs grows above the soil (Kumar et al. 2020 and Dubey et al. 2023).

***Allium porrum* (Leek)**

It is found in cultivable and wild form. The wild plant is commonly known as 'wild leek' or 'broadleaf wild leek. Wild populations produce bulbs up to 3 cm across. Plant grown up to 1 m tall, bulb ovoid, 3-4 cm broad, scaly and scape arising from the centre of the bulb (Dubey et al. 2023).

***Allium schoenoprasum* (Chives)**

Bulbs are narrowly ovoid, up to 2 cm long, 0.5 cm broad with scaly membranous scales. Leaves are 1-2 cylindrical. It looks like a tall tuft of grass. Umbels sub-globose, 3 cm across and have condensed flowers. Unequal pedicels, petals pink, 10-12 mm long, lanceolate and acute (Dubey et al. 2023).

Allium tuberosum

It is a perennial herbaceous plant, blooming late. It is famous for high medicinal value and herbal nature because of treating wide range of diseases and disorders potential, covering hypolipidemic and hypoglycemic characters. *Allium tuberosum* is used for the treatment of asthma, abdominal pain, diarrhoea, nocturnal emission and diabetes in folklore medicine. It is also known as 'garlic chive; Chinese chives; oriental garlic; Chinese leek' because of its mild flavour like garlic leaves. It produces 2 to 5 leaves which are 20-50 cm long and flowering scape of 25-60 cm height from underneath bulb along the rhizome. Umbels are dense flowered; sepals are white- rarely pink, 6-10 mm long, elliptic. Bulbs are cylindrical, 4-6 cm long, light brown when dried. It contains about 2.6% protein; 0.6% fat; 2.4% carbohydrate; 0.95% ash with small amounts of vitamins A; B_1 and C. Its flowers are white star shape with mild fragrance. It can be propogated by both seed or from clumps. Generally, its flowers are to be cut after blooming to avoid excessive spread. Its seeds are black colour and triangular shaped with a hard capsule. It is found in tremendous amounts in the region of Manipur; Mizoram; Meghalaya and Nagaland. Its leaves are sliced and fried. In market, its leaves can be sold by making the bundles as substitute of onion and garlic (Kumar et al. 2020 and Dubey et al. 2023).

Allium hookeri

It is an evergreen, herbaceous and grassy perennial known as Hooker chives or garlic chives. In contrast to other *Allium* species, it is devoid of bulb and characterized by white fibrous roots developed from a significantly reduced underground rhizome. The leaves are linear; fleshy and green in colour with prominent midribs and membranous basal leaves length of about 20-60 cm long and flowering scapes 20–60 cm tall. Many white or greenish-yellow flowers are crowded in umbels. July to October is its flowering time and the seeds ripen from August to November. The species is hermaphrodite and its pollination take place by bees and insects. Wide range of soils is found suitable for its cultivation but, light (sandy) to medium (loamy) moist soils with well-drainage capacity is best. It is suitable in all type of soil *p*H ranges. Its edible parts are the fibrous roots and the leaves which are mostly consumed as condiments or spices. Apart from consuming as food, it is been used in ethnotherapy of certain diseases and considered of great ethno botanic relevance to certain parts of the country. The therapeutic values of *A. hookeri* are attributed to the higher concentration of total phenols (2 g 100 g^{-1} dry weight) and phytosterols (0.5 g 100 g^{-1}) are known to lower the intestinal absorption of cholesterol in the body. Especially in NEH region, the major variety of the species shows broader leaf. A medium size herb leaves are 12-19 in numbers. It is common in Manipur; Arunachal Pradesh and Meghalaya. Leaves and bulbs cooked as vegetable. Bulbs are used in same way as onion (Kumar et al. 2020 and Dubey et al. 2023).

Allium chinense

It is a perennial herb commonly known as Chinese onion; Chinese scallion; Japanese scallion; Kiangsi scallion; oriental onion. Being served as side dish or as a nutritional supplement, it is traditionally used for treating stenocardia, heart asthma, and antiplatelet aggregation. Its footprint can be observed in local markets

of Meghalaya; Manipur; Mizoram; Nagaland and other NEH region of India. It grows up to 25 cm to 50 cm. It produces evergreen bulbs with hollow bright green leaves and grows in clumps forming many well-developed bulbs. Leaves are slender and thin-walled, 3 to 5 angled (not round) and less stiffly erect having solid seed stalk. Its flowers are lavender in colour with long pedicels, thick perianth segments and longexerted styles and stamens. Umbels are reddish purple flowers on a stalk 40-60 cm long. Unlike other *Allium* crops, it is on the side of the main growing shoot, not emerging from its centre. Usually, the umbel consists about 5 to 25 hermaphrodite flowers. The plant root can reach 45 to 50 cm depth and possesses a spherical bulb derived from a valve stem. Bulb is formed in autumn after summer dormancy with oval shape about 4 to 5 cm in diameter after the second or third year of growth. Grey-white or purple with a thin transparent skin, it has an excellent crispy texture that covers its white meat, which has a strong onion flavour at maturity. Both the leaf and roots are generally consumed as fresh and cooked. Locally it is known mostly for its medicinal values in mitigating and controlling various diseases and stresses like heart problems, headache and worms (Kumar et al. 2020 and Dubey et al. 2023).

Varietal Development of Onion in India

Systematic breeding work was started in 1960 in India at Niphad; Nashik; Maharashtra and afterwards at IARI, New Delhi. Pusa Red, N 2-4-1 and N – 53 like early varieties developed through selection are still performing well with pottential yield. The programme was further strengthened under coordinated project through SAUs and ICAR research institutes. As a result, 2 F_1 onion hybrids, 56 onion varieties and 6 multiplier onion varieties of have been developed as well as released. Onion is mainly *Rabi* season crop, but it can be cultivated in *kharif* and late *kharif* season also. So, season wise varieties have been recommended and developed. Varieties viz. Baswant – 780; N-53; Agrifound Dark Red; Arka Kalyan and Bhima Super have been developed for *kharif* season, Baswant – 780; Bhima Red; Bhima Shakti; Phule Samarth and Agrifound Light Red for late *kharif*, while N-2-4-1; Arka Niketan; Bhima Raj; Bhima Red; Bhima Kiran; Bhima Shakti; Agrifound Light Red; Pusa Red; Pusa Madhawi etc. have been developed for *rabi* season. Bhima Raj can be cultivated in *kharif* and late *kharif* season also. Varieties viz. Phule Safed; Pusa White Round; Pusa White Flat; Bhima Sweta; Agrifound White; Punjab Selection and Udaipur – 102 are white coloured can be cultivated during *rabi* season, while Bhima Shubra for *kharif* season (Mahajan et al. 2020).

Descriptions of varieties released from various research Institutes and SAUs are given in the following table.

Sr. No.	Variety	Institute or Organization	Features
1.	N-53	Department of Agriculture, Maharashtra	Red coloured *kharif*variety released in 1975, but now breeder seed is not available.
2.	*N-2-4-1		*Rabi* and late *kharif*variety released in 1985.
3.	*N-257-9-1		White coloured *rabi* variety released in 1985.
4.	Baswant -780	Mahatma Phule Krushi Vidyapeeth, Rahuri (M.S.)	Red colured *kharif*and late *kharif* variety released in 1989.
5.	Phule Safed		White colured late *Kharif* and *Rabi* variety released in 1994.
6.	Phule Suvarna		Yellow coloured *rabi* and late *kharif*released in 2001.
7.	*Phule Samarth (S-1)		Red coloured *kharif*and late *kharif* released in 2006.
8.	Pusa White Flat	IARI, New Delhi	White *rabi* variety released in 1975.

9.	Pusa White Round		White *rabi* released in 1975.
10.	Early Grano		Yellow, late *kharif* and *rabi* released in 1975. It is Long Day.
11	Brown Spanish		Brown variety released in 1975 for hills. It is Long Day type.
12.	*Pusa Red		Red, late *kharif* and *rabi* variety released in 1975.
13	Pusa Shobha		It is a new variety having high dry matter (15.24 g 100 g^{-1}); pungency (4.61 µmole 100g^{-1}); antioxidant (2.53 µmole TE 100 g^{-1}); total phenol (18.11 mg 100 g^{-1}) and TSS (16.41°B) suitable for dehydration has large scope in domestic as well as foreign market.
14.	*Pusa Ratnar		Red, *rabi* variety released in 1975.
15.	*Pusa Madhavi (Line-120)		Red, *rabi* variety released in 1987.
16.	*Selection 126		Brown coloued *rabi* variety released in 2012.
17.	Arka Pragati	Indian Institure of Horticultural Research, Bangalore	Red, *kharif*and *rabi* variety released in 1984.
18.	*Arka Niketan		Red, late *kharif* and *rabi* variety released in 1987.
19.	*Arka Kalyan		Red, *kharif* variety released in 1987.
20.	Arka Pitamber		Yellow coloured variety released in 2006 for kharif and rabi seasons, suitable for export market. It is developed through pedigree selection from the cross U.D. 102 x IIHR 396. It tolerates purple blotch, basal rot infection as well as thrips infestation. Its bulb can be stored up to 3 months. It matures in 140 DAT and yields 35 t ha^{-1}.
21.	Arka Bindu		Red*, kharif,* late *kharif* and *rabi* variety released in 2006.
22.	Arka Ujjwal (Multiplier onion)		Dark red, *rabi* variety released in 2010. It gives bulb yield 20-25 t ha^{-1} and matures in 85 DAT.
23.	Arka Swadista		White, *rabi* variety released in 2010 which is suitable for fermented preservation processing and gives bulb yield 16-18 t ha^{-1} in 105 DAT.
24.	Arka Kirthiman (F1)		A red bulb coloured F1 between MS-65 x Sel. 13-1-1 suitable for *kharif* and *rabi* seasons which tolerates purple blotch, basal rot infections and thrips infestation. Its bulbs can be stored 4-5 months. It yields 47 t ha^{-1} and matures in 125-130 DAT.
25.	Arka Sona		Yellow, *rabi* variety released in 2011 suitable for export. It yields 45 t ha^{-1} and matures in 120 DAT.
26.	Arka Bhim (Tri-parental synthetic)		Red, *rabi* variety released in 2011, gives average bulb yield 47 t ha^{-1} and matures in 130 DAT.
27.	Arka Akshay (Tri-parental synthetic)		Dark red, rabi variety released in 2011 gives average bulb yield 45 t ha^{-1} and matures in 130 DAT.
28	Arka Vishwas (Rose onion)		Dark red, *kharif* and *rabi* variety suitable for export released in 2011. It gives bulb yield tha^{-1} and matures in 115 DAT.

29	Arka Lalima		A red coloured F1 between MS-48 x Sel. 14-1-1 suitable for *kharif* and *rabi* seasons which is tolerance to purple blotch, basal rot and thrips. Its bulbs can be storaed 4-5 months. It yields 50 t ha^{-1} and matures in 130-140 DAT.
30.	Hissar- 2	CCS HAU, Hisar	Red, *rabi* variety released in 1976.
31.	*HOS-1		Red, *rabi* variety released in 2006.
32.	*Agrifound Light Red	National Horticultural Research and Development Foundation (NHRDF) Delhi	Red, *rabi* variety released in 1988 and recommended all over the country. Duration about 100-120 DAT. Average yield 30-32.50 t ha^{-1}.
33.	*Agrifound Dark Red		Red, *kharif* variety released in 1966, recommended for all over the country.
34.	*NHRDF Red (L-28)		Red, *rabi* variety released in 2006.
35.	* NHRDF Red-2 (L-355)		Red, *rabi* variety released in 2012 for zones-III (Delhi, UP, Haryana, Bihar and Punjab), zone-IV (Rajasthan and Gujarat) and zone-VI (MS, Karnataka and AP). Duration is 100-120 DAT. Average yield 30-35 t ha^{-1}.
36.	NHRDF Red-3 (L-652)		Recommended for *rabi* season for all over the country. Duration is 120-130 DAT. Average yield 35-40 t ha^{-1}.
37.	Agrifound Rose		Red, *rabi* variety released in 1987.
38.	NHRDF-Red-4		Dark red variery has been notified by the GOI for growing in *rabi* season in zone III (UP, Bihar, WB and Imphal). Duration 110-120 DAT. Its keeping quality is good. Average yield 35.0-40.0 t ha^{-1}.
39.	NHRDF Fursungi		Red variety has been notified by the GOI for cultivation in *rabi* season Zone-II (Delhi, Rajasthan, Haryana, J & K and Punjab) and Zone – V (Gujarat & M.S.). Duration 110-120 DAT. The keeping quality of bulbs is good. Average yield 38.0-40.0 t ha^{-1}.
40.	Line – 883		Dark red line is recommended for cultivation in *kharif* and early *kharif* seasons all over India. Duration 85-90 DAT. In case of direct sowing maturites in 80-85 days. Average yield 30.0-32.5 t ha^{-1}.
41.	Agrifound Red (Multiplier)		Red, *kharif* and *rabi* variety released in 1987.
42.	Agrifound White		White, *rabi* variety released in 1994.
43.	VL-67 (Long Day)	VPKAS, Almora	Red coloured variety released in 1973, recommended for hills.
44.	*VL-3 (Long Day)		Red coloured variety released in 1990, recommended for hills.
45.	Udaipur 101	RAU, Bikaner Campus, Updaipur	It is red coloured variety recommended for *rabi* season.
46.	Udaipur 102		White coloured *rabi* variety.
47.	Udaipur 103		It is red coloured variety recommended for *rabi.*
48.	*PKV White	PDKV, Akola	White coloured *rabi* variety released in 2009.

49.	Gujarat White Onion (GWO) - 1	JAU, Junagarh	White, *rabi* variety released in 2000.
50.	Gujarat Junagadh Red Onion-11(GJRO-11)		Red variety recommended for *rabi* season.
51.	Kalyanpur Red Round	CSAUAT, Kanpur	Red, *rabi* variety released in 1983.
52.	Punjab Selection	PAU, Ludhiana	Red, *rabi* variety released in 1973.
53.	*Punjab Red Round		Red, *rabi* variety released in 1993.
54.	Punjab-48 (S-48)		White, *rabi* variety released in 1978.
55.	Punjab White		White, *rabi* variety released in 1998.
56.	*Punjab Naroya (PBR-5)		Red, *rabi* variety released in 1997.
57.	Punjab Selection		Red, *rabi* variety released in 1973.
58.	Co-1 (Multiplier)	TNAU, Coimbatore	Red variety for *kharif* and *rabi.*
59.	Co - 2		Red variety released in 1978 for *kharif* and *rabi*
60.	Co - 3		Red variety released in 1982 for *kharif* and *rabi*
61.	Co - 4		Red variety released in 1984 for *kharif* and *rabi*
62.	Co - 5		Red *kharif* and *rabi* variety, propagated by seed also.
63.	MDU-1		Red variety released in 1982 for *rabi.*
64.	Rajasthan Onion-1 (RO-1)	RARI, Durgapura	Red variety released in 2004 for *rabi.*
65.	Arpita (RO-59)		Red variety released in 2005 for *rabi.*
66.	RO 252		Red variety released in 2010 for *rabi.*
67.	*Bhima Super	ICAR-Directorate of Onion and Garlic Research (DOGR), Rajgurunagar, Pune, Maharashtra.	Red variety released in 2006, recommended as *kharif,* late *kharif* and *rabi* variety for Delhi; Gujarat; Haryana; Karnataka; MP., MS; Rajasthan; TN; Punjab and Odisha.
68.	*Bhima Raj		Red variety released in 2007, recommended as *kharif* and late *kharif* variety for Gujarat; MS and Rajasthan, while as *rabi* for Delhi; Gujarat; Rajasthan and Haryana.
69.	*Bhima Red		It is released in 2009, recommended as *kharif* variety for Gujarat; MS; Rajasthan; Delhi; Haryana; Karnataka; MP; TN; Punjab, while as *rabi* for MS and MP.
70.	*Bhima Shakti		Red variety released in 2010 and recommended for *rabi* season in AP; Bihar; Chhattisgarh; Delhi; Gujarat; Haryana; Karnataka; MP., MS; Odisa; Punjab; Rajasthan and UP.
71.	*Bhima Kiran		Red variety released in 2010 for *rabi.*
72.	*Bhima Shweta		White variety released in 2010, recommended as *kharif* variety for Chhattisgarh; Karnataka; MS; Rajasthan; MP; Odisa and TN., while as *rabi* for AP; Bihar; Chhattisgarh; Delhi; Haryana; Karnataka; MP; MS; Odisa; UP and Punjab.

73	*Bhima Shubhra		White variety released in 2010, recommended for *kharif* season for Chhattisgarh; Gujarat; Karnataka; MP; MS; Odisha; Rajasthan and TN. It can be also cultivated during late *kharif* season.
74	*Bhima Dark Red		Red variety released in 2012, recommended as *kharif* variety for Gujarat; MS; Rajasthan; Delhi; Haryana; Karnataka; MP; TN and Punjab.
75	*Bhima Safed		White variety released in 2014, recommend ed for *kharif* season for Chhattisgarh; Gujarat; Karnataka; MP; MS; Odisha; Rajasthan and TN.
76	*Bhima Light Red		Red variety released in 2015 for *rabi* season.
77	Bhima Prasanskaran		It has high TSS more than 17% suitable for processing for *rabi* season in short day conditions. Average yield of 250 to 300 q ha^{-1}. Recently recommended by CVRC for Gujarat; Maharashtra; Karnataka; Telangana; Andhra Pradesh and Tamil Nadu.
78	Phule Swami (RHROR-12)	Western Maharsahtra	AICRP on Vegetable Crops, MPKV, Rahuri (MS).
79	CITH-Red Grem (CITH-O-2)	J and K	ICAR-CITH, J and K, Srinagar, J and K.

Source, Mahajan et al. 2020, Sable et al. 2021; Sable and Sonpure, 2023; 2 Days (26-27th May, 2020) National Webinar on Approaches Towards Onion Cultivation organized by KVK, S. D. Agricultural University, Khedbrahma (Guj.), E-Published by: *Indian Society of Alliums* (ICAR-DO&GR, Rajgurunagar, Pune, MS.), https://www.iihr.res.in/varieties.

* These varieties have been releasing through All India Coordinated Research Project on Vegetables or All India Network Research Project on Onion and Garlic. Others are identified at institute level.

In India, the varieties developed by various organizations have been tested at different locations under All India Coordinated Vegetable Improvement Project and All India Network Research Project on Onion and Garlic and based on their performance these varieties have been recommended for different zones. So far thirty varieties have been recommended for cultivation under specific agro-climatic zones.

Onion Varieties Recommended for Cultivation and Released through AICRP & AINRPOG.

S.N.	Varieties	Organization/ Institution	Recommended Zones	Year of identification
1	Punjab Selection	PAU, Ludhiana	IV, VII & VIII	1975
2	Pusa Red	IARI, N. Delhi	IV, VII, VIII	1975
3	Pusa Ratnar	IARI, N. Delhi	IV & VI	1975
4	S-131	IARI, N. Delhi	-	1977
5	N-257-9-1	Agril. Dept., M.S.	-	1985
6	N-2-4-1	Agril. Dept., M.S.	-	1985
7	Line-102	IARI, N. Delhi	I, IV, VI, VII	1987
8	Arka Kalyan	IIHR, Bangalore	IV, VI, VII, VIII	1987
9	Arka Niketan	IIHR, Bangalore	IV, VII, VIII	1987
10	Agrifound Dark Red	NHRDF, Nashik	IV	1987

11	VL-3	VPKAS, Almora	I	1990
12	Agrifound Light Red	NHRDF, Nashik	VI, VIII	1993
13	Punjab Red Round	PAU, Ludhiana	IV	1993
14	PBR-5	PAU, Ludhiana	VI	1997
15	L-28	NHRDF, Nashik	IV & VII	2006
16	HOS-1	HAU, Hissar	VI	2006
17	Bhima Raj	NRCOG, Rajgurunagar	VI	2007
18	Bhima Red	DOGR, Rajgurunagar	VII for rabi & II, V & VI** for *kharif*	2009 & 2012
19	PKV White	PDKV, Akola	VI	2009
20	RHOR-S1(Phule Samarth	MPKV, Rahuri	VI, VIII	2009
21	Bhima Kiran	DOGR, Rajgurunagar	III & VI*	2010
22	Line-355	NHRDF, Nashik	III, IV & VI*	2010
23	Bhima Shakti	DOGR, Rajgurunagar	III, IV, V, VI*	2011
24	Bhima Shweta	DOGR, Rajgurunagar	III, V, VI* for rabi & IV, V, VI** for *kharif*	2011, 2012
25	Sel-126	IARI, N. Delhi	III, IV, V*	2011
26	Bhima Super	DOGR, Rajgurunagar	II, IV, V & VI** for *kharif*	2012
27	Bhima Dark Red	DOGR, Rajgurunagar	II, IV, V & VI.**	2012
28	Bhima Shubra	DOGR, Rajgurunagar	IV, V & VI** for *kharif*	2012
29	Bhima Safed	DOGR, Rajgurunagar	IV, V & VI** for *kharif*	2014
30	Bhima Light Red	DOGR, Rajgurunagar	VI	2015

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Details of the Zones under AICRP Vegetables

Zone I = Himachal Pradesh & U.P. Hills, Zone II = West Bengal & Assam, Zone III = Sikkim, Meghalaya, Manipur, Nagaland, Mizoram, Tripura, Arunachal Pradesh and Andaman & Nicobar Islands, Zone IV = Punjab, Tarai region of U.P. & Bihar, Zone V = Chhattisgarh, Orissa & Andhra Pradesh, Zone VI = Rajesthan, Gujarat, Haryana & Delhi, Zone VII = Madhya Pradesh & Maharashtra, Zone VIII = Karnataka, Tamil Nadu & Kerala.

* New zones decided during 2010 under AINRPOG: Zone III = Delhi, UP, Haryana, Bihar and Punjab, Zone IV = Rajasthan & Gujarat, Zone V = MP, Chhattisgarh & Orissa, Zone VI = Maharashtra, Karnataka and Andhra Pradesh.

**Further zones were reclassified in 2011 comprising following centres in different states: Zone I: Srinagar, Almora, Mukteshwar, Palampur, Ooty, Zone II: Jammu, Ludhiana, Delhi, Karnal, Hissar, Durgapura, Zone

IV: Jabalpur, Raipur, Chiplima, Akola, Jhalawar, Zone V: Junagadh, Nasik, Rahuri, Pune, Zone VI: Bagalkot, Bangalore, Coimbatore, Dharwad.

Crop Improvement

Onion is highly cross – pollinated crop so providing a scope for new population improvement methods because natural variability is created constantly. In genetic studies, different gene actions and gene combinations identified are being utilized for generating new varieties and developing material for developing new hybrids. Information on the nature and extent of genetic variability and degree of transmission of traits is of paramount importance in enhancing the efficiency of selection. Knowledge of correlations among various characters and their relative contribution to yield is useful for multiple trait selection. Worldwide different group of scientists are inventing the new techniques for population improvement in onion utilizing conventional and new techniques for developing varieties and hybrids suitable for different purposes which descriptions are given in the following table.

Sr. No.	Variety released	Method of Crop Improvement	Scientists Involved and References
1	N – 53	Mass selection from Nashik (M.S.)	MPKV, Rahuri, 1975
2	Punjab Selection	Mass selection from indigenous material collection from Punjab	PAU, Ludhiana, 1975
3	Pusa White Flat	Mass Selection (Local Collection)	IARI, New Delhi, 1975
4	Pusa White Round	Mass Selection Local collection (106)	IARI, New Delhi, 1975
5	Co 2	Mass Selection (Collection from Tamil Nadu)	TNAU, Coimbatore, 1978
6	Punjab – 48	Mass Selection (Collection from Punjab)	PAU, Ludhiana, 1978
7	Pusa Ratnar	Mass Selection (Selection from Red Granex from USA)	IARI, New Delhi, 1978
8	Pusa Red	Mass Selection (Local Collection)	IARI, New Delhi, 1978
9	Co 3	Mass Selection (Collection from TN)	TNAU, Co., 1982
10	Kalyanpur Red Round	Mass Selection (Collection from U P)	CSUAT, Kanpur, 1983
11	Arka Pragati	Mass Selection (Nashik, M.S. Collection)	IIHR, Bangalore, 1984
12	N – 2 – 4 – 1	Mass Selection (Collection from Pune, MS)	MPKV, Rahuri, 1985
13	Arka Niketan	Mass Selection (Mass selection from a local collection IIHR – 153)	IIHR, Bangalore, 1987
14	Agrifound Dark Red	Mass Selection (Collection from Nashik, Maharashtra)	NHRDF, Nashik, 1987

15	Pusa Madhavi	Mass Selection (Collection from Muzaffarnagar, U P)	IARI, New Delhi, 1987
16	Arka Kalyan (Sel-14)	Mass Selection (Mass selection from a local collection IIHR – 145)	IIHR, Bangalore, 1987
17	Baswant – 780	Mass Selection (Collection from Pimpalgaon, Maharashtra)	MPKV, Rahuri, 1989
18	'VL Piaz 3'	3 cycles of Mass selection after F2 of cross 'In-13 x L-43'	Mani et al. 1999
19	Genetic analysis in six generations (P1, P2, F1, F2, B1 and B2) of four onion crosses *viz*., PBR 138 x AN 187, PBR 139 x AN 184, PBR 139 x AP 195 and PBR 140 x AN 184	Reciprocal recurrent selection: Exploit all gene actions simultaneously to develop a new resistant line/ variety, being best method to improve trait of resistance to purple blotch disease.	Evoor, et al. 2007,
20	Arka Pitambhar	Pedigree selection from the cross U.D. 102 x IIHR-396	IIHR, Bangalore http://www.iihr.res.in/frmVarities.aspx
21	Bhima Super	Rigorous mass selection for single centeredness & bulb shape	Lawande et al. 2007
22	Bhima Red and Bhima Raj	Single bulb selection up to three generations followed by mass selection for all the three seasons viz. *kharif,* late *kharif* & *rabi*	Lawande et al. 2009
23	Bhima Shakti and Bhima Kiran	Mass selection for late *kharif* and *rabi* season with better storability and mass selection for *rabi* with good keeping quality	Lawande et al. 2010[a] & Lawande et al. 2010[b]
24	Bhima Shweta	Selection of elite lines from germplasm followed by random matting and mass selection for *rabi* season white onion	Mahajan et al. 2010
25	Bhima Shubra	Selection of white segregating bulb from red germplasm followed by mass selection for white populations for *kharif* & late *kharif* season	Mahajan et al. 2010

Mahajan et al., 2020

Mass Selection and Combinations of Other Methods

A number of experiments have been reported on inheritance of yield and maturity, many of which were concerned with the estimation of combining ability in various populations. In general, diallel crossing designs have been used for this type of estimation. Joshi and Tandon, in a set of crosses between male sterile and

pollinator lines, demonstrated significant GCA effects for yield in the male sterile lines with evidence of SCA for one particular cross (Mahajan et al. 2020 and Joshi and Tandon, 1976). A major contribution to onion breeding has been the development of new open pollinated (OP) varieties using a range of population improvement methods. OP varieties are defined as genetically variable populations, which are maintained and multiplied by mass pollination in isolation (Mahajan et al. 2020).

The simplest one being mass selection, starting with a chosen parent population, the best approximately 1 to 5% of mother bulbs of the desired type are selected at harvest or following storage and subsequently replanted to produce flowering plants which are mass pollinated together in isolation. Several cycles of mass selection are usually employed before larger scale multiplication of selected improved population to produce a new variety. Success depends upon presence of the required genetic variability in present population on which selection can operate. A refinement to mass selection is stratified mass selection, whereby the field plot of bulbs grown for selection is subdivided into equal sized areas and same proportion of selected bulbs of desired types chosen from each area. It helps to make allowance for the effect of variable growing conditions within the field plot on appearance of the mother bulbs and correspondingly to increase the chance of picking out heritable variation during the selection process. Arka Kalyan (Sel 14) was developed in 1987 through vigorous mass selection from IIHR 145 Globe shaped bulbs with medium large size. Deep red-coloured outer scales and fleshy succulent internal scales. Average bulb weight 130-180 g. Pungent with TSS 11-13%. Moderately resistant to purple blotch caused by *Alternaria porii,* seed yield 8 q ha^{-1} and is suitable for *kharif* season. It gives yield 47 t ha^{-1} and matures in 140 DAT.

Additive gene effect for dry matter content, bulb size and maturity and additive and non-additive gene effect for bulb yield and number of leaves per plant plays important role. Selections 11–1–1 and IIHR–25 are reported to be purpule blotch resistant from IIHR, Bangalore and Punjab Red Round and Punjab Narroya (PBR 5) from PAU tolerant to purple blotch (Mahajan et al. 2020 and Singh, 1997).

Mass selection exploits general gene effect and additive x additive type of gene interaction in a cross combination 'In-13 x L-43'. Three cycles of mass selection of the F2 of this combination led to the development of an improved high yielding onion strain 'VL 3'. This high yielding opens pollinated variety, designated as 'VL Piaz 3' identified by All India Vegetable Improvement workshop during 1990 for hills and plains of U.P. Recurrent mass selection method found to be more efficient up to 86%. Two breeding methods could lead to improved quality characteristics particularly bolting. Mass selection was more efficient in selecting against bolting. The doubling and maturity characters were unchanged by either of the two breeding methods (Mahajan et al. 2020 and Mani et al.1999).

Bhima Super developed for single centeredness up to 7 generations by rigorous mass selection which is able to produce more than 95% single centred bulbs with uniform desirable shape of bulb for *kharif* season (Lawande et al. 2007). Bhima Red and Bhima Raj developed by single bulb selection up to 3 generations from Basawant 780 followed by mass selection (Lawande et al. 2007; Lawande et al. 2009). Bhima Shakti (Red) and Bhima Kiran (Light red) developed through mass selection for late *kharif* and *rabi* and *rabi* season, respectively along with good keeping quality (Lawande *et al.* 2010). Bhima Sweta a white onion variety suitable for *rabi* season developed by selecting white onion elite lines from germplasm followed by random matting and further mass selection for three generation (Mahajan et al. 2010). Bhima Shubra variety is suitable for *kharif* and late *kharif* season in Maharashtra was developed by selecting white segregating bulbs from red onion germplasm line which was further purified and developed through mass selection (Mahajan et al. 2010).

Pedigree Selection

Arka Pitambar developed through pedigree selection of cross U.D. 102 x IIHR-396 by IIHR, Bangalore, with medium size (5.2 -6.0 cm) bulbs having globe shape and thin neck. Mild pungency with total soluble soilds (TSS) 11% and total sugar 9.81%. It also founds tolerant to purple blotch, basal rot diseases and thrips (Mahajan et al. 2020).

Breeding for Seasonal Adaptability

In India, onion is commercial planted between 12 to 25^0 N latitude. *Kharif* crop cultivated during hot and humid months and become ready for harvest when temperature is low. The bulbs are not mature as growth continues due to shorter days and cooler temperature. The bulbs of *kharif* season do not have good storability. Although, the day length during this period is slightly more than *rabi*, the critical day length available is around 11-11.5 hrs due to cloudy weather. Through hundreds of selections the types, which can respond to warm and humid days with 11-11.5 hrs, have been identified and maintained by the farmers. From the same material superior genotypes like N 53; Agrifound Dark Red; Basawant 780; Bhima Super; Bhima Shubra and Arka Kalyan have been developed. Recently due to late monsoon or irregularities of rain in *kharif* season there has been shift in planting from *kharif* to late *Kharif*. Availability of irrigation water from September to February, failure of *kharif* crop due to high rainfall coupled with high incidence of diseases and pest and poor storage of *kharif* produce, farmers in Western Maharashtra are inclining towards late *kharif* season commonly called as *Rangda* onion. In, October, seedlings are transplanted and bulbs mature and become ready for harvest in January-February. Bulb initiation and bulb development favours due to low temperature during November -December. Bulb maturity facilitates due to warm days during January-February, as the day length become available again 11-11.5 hrs. It yields high with good bulb size but bolting per cent and doubling of bulbs (twins) is very high thereby reducing marketable yield. Further, storability of bulbs is also low as compared to *rabi* produce. Varieties viz. Bhima Shakti and Bhima Shubra developed by DOGR, Rajgurunagar and Phule Samarth by MPKV, Rahuri recently recommended for late *kharif* season. *Rabi* season seedlings are transplanted in end of the November or December, low temperatures (20- 25 ^{0}C) during December-January favour bulb initiation under again short-day conditions i.e. 11-11.50 hrs. Bulb growth and maturity is in February and March where nights are cool and days are warm (35-40 ^{0}C). High temperatures during April-May hasten maturity. There are better curing of neck and such bulbs store well up to 5-6 months. Almost all genotypes grown in this season are of light red coloured. But now a day demand is changing towards dark red onions during *rabi* season also. Hence, there is need to develop dark red onion varieties with good storage during *rabi*. Bhima Shakti; NHRDF Red 3; NHRDF Red 4 are among these recently recommended have medium to dark red bulbs with good keeping quality for *rabi* season. In, hills of Uttar Pradesh, Himachal Pradesh, *rabi* crop is transplanted in October-November and harvested in June-July, while summer crop is planted in February-March and harvested in August-October. In hills, days are longer (>13 hrs) and temperatures are cool. Duration is long (>7 months). Due to congenial climate, growth and development is very good, bulb size big and therefore yields are high. Granex types with yellow colour varieties are grown in hills. In India pink skinned and pungent types are preferred essentially for cooking, due to its strong flavour. In contrast for salad, yellow skinned and sweet onion varieties of western countries are not liked in India and hence long day onions do not find flavour. Incidentally, high productivity in western countries is favoured by long maturity season and long day photoperiodic conditions, which in turn promote high quality and very compact bulbs. Tropical onions maturing under short day conditions and short growing season yield less with somewhat poor-quality bulbs. Hence, Indian average is only 10-12 t ha^{-1} as compared to 30 t ha^{-1} in countries located between 25 to 30 ^{0}N latitude (Mahajan et al. 2020 and Sheshadri and

Chaterjee, 1996). Synchronized (Staggered) planting in different seasons warrantees for steady supply of onion in the country. Unfortunately, there is limited Varietal wealth for *kharif* and late *kharif* season. Early maturity, dark red colour and resistance to *Colletotrichum* and purple blotch blight are the need of *kharif* season. Further, the varieties need some dormancy for effective marketing. Recommended varieties like N 53, Basawant 780, Arka Kalyan, Agrifound Dark Red and Phule Samarth suffer from these drawbacks. But, at present N 53 is not available because of its seed non-availability. Late *kharif* season is becoming more popular in Maharashtra due to high yield and less diseases infection and pest's infestation. High per cent of bolting and poor storage are the limited factors. There is no suitable variety in dark red as well light red colour at the time of marketing or export is the requirement. Some light red-coloured varieties meet the standards; however, there is need to develop dark red-coloured varieties for *rabi* season also.

Breeding for Processing Qualities

Dehydration industries require white, globose onion bulbs with high TSS (>18%). Indian white onion genotypes are having TSS range between 11-13%. Ideal variety for dehydration should be high yielding, pure white, globose shaped, thin necked, free from greening and moulds, high pungent, with high TSS and field tolerance /resistance to diseases and pests. In order to continuous supply, varieties should have wider seasonal adaptability. An Indian variety are short day typed, matures in 90-120 DAT having basically low TSS (10-14%). Some of the long day varieties which mature in 150-180 days offer high TSS range from 15 to 24%. But long day varieties do-not produce bulbs under Indian short-day conditions. However, an intermediate short-day variety produces good bulbs but seed production is not possible under plains. In plains of India, varieties mature in high temperature, which facilitates high sulphur built up and therefore Indian varieties are more pungent. In India attempts were made for development of white onion varieties by different research institutes which descriptions are given in the following table.

Sr. No.	Name of Variety	Orgnization/ Institute	TSS %	Av. yield tha^{-1}
1.	Pusa White Round	IARI, New Delhi	11.13	30.0 – 32.5
2.	Pusa White Flat	IARI, New Delhi	10.00	32.5 – 35.0
3.	Udaipur 102	RAU, Udaipur	10.06	30.0 – 35.0
4.	Agrifound White	NHRDF, Nashik	10.76	20.0 – 25.0
5.	Phule Safed	MPKV, Rahuri	10.13	25.0 – 30.0
6.	PKV White	PDKV, Akola	09.55	25.0 – 30.0
7.	Gujarat White	JAU, Junagadh	-	30.0 – 32.5
8.	N-257-9-1	Dept. of Agril., MS.	10.00	25.0 – 30.0
9.	Punjab-48	PAU, Ludhiana	11.00	30.0 – 32.5
10.	V-12	Jain Food Park	15.00	35.0 – 40.0
11.	Nimar Local	Land Race, M.P.	12.50	25.0 – 30.0
12.	Talaja Local	Land Race Bhavnagar	12.00	25.0 – 30.0

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Indian varieties and land races do-not offer TSS. range more than 12%, while White Creole variety introduced by Jain Food Park Industries, Jalgaon, which further subjected to selection for high TSS and developed V-12 variety having TSS range 15-18%. This variety is under contract production for processing but seed production is not possible under Indian plains (Mahajan et al. 2020). National Resaerch Centre for Onion and Garlic, Rajgurunagar, initiated special programme since 1998 through selfing and massing from available

germplasm for development of white onion variety for high TSS. About 7199 bulbs were examined for TSS range in the year 2000 and only 2.72% bulbs recorded TSS more than 14%. 109 bulbs showing TSS range from 15 to 23% were selfed and populations were developed. Only 30 populations having 16 to 19% TSS are advanced, after rejecting poor performing populations. In 4th generation of selection cycle, more than 75% bulbs having average TSS about 18% or even more achievement is possible in about 15 populations in short day onion. Development of high TSS. open pollinated varieties within 2 to 3 years suitable for *rabi* and late *kharif* would be possible. Further, the programme for incorporation of high TSS genes from long day and intermediate exotic cultivars to Indian genotypes is initiated in temperate region of Srinagar. Mutation breeding also being tried for the same, which resulted into three white mutants developed through chemical and physical mutagens viz. 22-5-1-1, 22-9-2-2 and 106-13-1-1 showing TSS range 25-30% (Mahajan et al. 2020). This excellent material never reflected further in the form of either commercial variety or breeding material for varietal improvement. Recently in 2024 India's high TSS (>17%) first white onion variety Bhima Prasanskaran has been notified by CVRC for *rabi* season suitable for processing.

Breeding for Export Quality Onion

India is number one in export of onion followed by Netherlands. India's export is mostly to South East Asian and Gulf countries. Dark red and light red onions with globe shape are mostly preferred with various diameter sizes. The present practice of export is grading and packing from the total bulk arriving in various onion markets. Uniformity its shape, size and colour is seldom attained, as there is no systematic control over planting of required varieties. Further, there is lack in varieties, which can suit to exclusive markets. European markets require yellow or brown onion with big size. There are hardly any indigenous varieties, which can meet to these standards. National Resaerch Centre for Onion and Garlic, Rajgurunagar has initiated work in this direction and recommended Mercedes, Linda Vista, Cougre and Collina from exotic material for growing in late *kharif* season. There is need of time to develope dark red and light red colour varieties exclusively for export markets. Breeding work using long day and intermediate day exotic varieties with aim to transfer desirable characters in short day onion varieties is undertaken by DOGR in collaboration with CITH, Srinagar. Crosses were made and further selections for desirable characters were done which is further followed by mass selection (Mahajan et al. 2020).

Breeding for Yellow Onion

Though yellow onion varieties do not prefer in India, but these having demands in European international market. For export, bigger bulb size i.e. more than 6.0 cm in diameter, less pungent and single-centered bulbs characters are the minimum requirements. That's why; more work has been done in European countries and USA, whereas, in India, research on onion has not been of any great significance. In India, very less work has been done for development of yellow onion varieties, especially for export. Only two varieties developed, like Phule Swarna from MPKV, Rahuri and Arka Pitambar from IIHR, Bangalore and were released at the state / institute level. These varieties yield less as compared to commercial red onion varieties, evident is that, Arka Pitambar shows lowest bulb diameter (4.2 cm) during *kharif* season which reflects into low yields (Mohanty et al. 2000).

Varietal Development Related to Climate Change

Global warming and pollution are responsible for climate change has become major constrains to the crop scientists for mitigation of its effect on crop. Effect on total ecology and subsequently on certain important

commodities is really not being studied. No systematic studies are conducted regarding this. However, visible effect on distribution of rainfall has been noticed, which had exercised effect on increasing disease and pest in *kharif* onion. *Kharif* onion is a very sensitive and crucial crop in meeting domestic supply from October to January. Failure of *kharif* crop leads to hike in prices. During, October-January sudden increase in temperature in *rabi* season result in poor bulb initiation and bulb development of *rabi* onion. Incidence of thrips and mites increases during dry weather with high temperature. Keeping quality of onion bulbs reduces during March-April-May due to very high temperatures. Work on development of photo and thermo insensitive varieties is undertaken at DOGR, Rajgurunagar to overcome the changing climatic situations. Some of the germplasm founds promising and can be grown in all the three seasons *viz*. *kharif*, late *kharif* and *rabi* is being exploited for such situations. Bhima Super; Bhima Red; Bhima Dark Red; Bhima Sweta are among these but keeping quality in *rabi* season is less up to three months only. In short day onion, normally bulb initiation takes place between 10-15 ^{0}C night and 20-25 ^{0}C day temperatures. Bulb development founds best at 18-20 ^{0}C night and 25-30 ^{0}C day temperatures and for maturity day temperatures between 35-38 ^{0}C is required. Throughout world, lots of varieties have been developed but they are restricted for cultivation to specific season or climate and are sensitive to climate change. In India, about 65 varieties have been developed also but they cannot be grown in different photoperiod or temperature conditions. Even fluctuating climate is affecting within the season of cultivation. Looking to these challenges' efforts were initiated to develop varieties which can sustain environmental vagaries and different varieties were tested in all the three seasons from 2002 to 2007 in red onion and white onion germplasm were identified 2002 – 2008 tested for at least years and three seasons. The results were encouraging and variety Bhima Super and Bhima Red was the outcome of the findings and were found promising (Lawande et al. 2007 and Lawande et al. 2009). In white onion out of 75 lines, 8 lines found suitable for all the three seasons. These varieties can be grown from sunshine hours of 2.48 to 9.66 hrs with monthly average temperature range 10.51 to 36.34 ^{0}C and rainfall from 0 to 273.71 mm. They can be cultivated in all the three seasons viz. *kharif* (May to October); late *kharif* (August to February); *rabi* (October to April). These varieties have less effect of photoperiod and temperature and can sustain up to greater extent in changing climate with little modifications in cultivation and management practices. This shows a path and has scope to identify potential germplasm which can be exploited for development of varieties to face environmental challenges in 21th century with the aim to develop photo and thermo insensitive varieties of onion for different locations. Besides this Bhima Shakti a red onion variety has been recommended for cultivation during late *kharif* and *rabi* in 2011 and Bhima Shubra a first white variety for *kharif* and late *kharif* 2010 (Mahajan et al. 2020).

Selfing and Massing

It is good method for improvement in a crop, where inbreeding depression is common, suggested by Jones and Mann (1963). Improvement in a variety can be affected by selfing followed by massing which procedure is narrated below.

1st year (bulb crop)

Select 100 best bulbs of desired type.

2nd year (seed crop)

Grow selected bulbs, self-one or more umbels per plant to initiate a separate line each.

3rd year (bulb crop)

Grow the progenies of each inbred line separately. Discard the poor performing lines during the growing season, at the time of harvest or storage. Select at least 25 best lines and keep 15-20 bulbs of each for selfing and open pollination next year.

4th year (seed crop)

Self-pollinate 1-2 umbels in each plant and allow others to open pollinate. Mass open pollinated seed and increase for large scale production for more than 2 generations in order to avoid much inbreeding depression.

5th year (bulb crop)

Grow the selfed progeny separately. Select again the best 25 lines and 15- 20 bulbs from each linea as above in the 3rd year.

6th year (seed crop)

Composite the bulbs of all selections and plant in a field or in a cage for free pollination in between the unrelated lines. The open pollinated seed can be massed and increases as foundation seed (Singh and Pal, 2022).

Soil and Climate

Onion can be grown in all types of soils. However deep; friable loam and alluvial soils with pH 6.0 - 7.5; EC 4.0 dS /m; good drainage; water holding capacity and organic matter content is the best. Addition of well decomposed organic manure helps in improving soil fertility status besides improving the soil physical properties and availability of microorganisms (Sable and Sonpure, 2023). Onions are very much sensitive to the effects of high-water table so well drained soils are best. Crop is more sensitive to highly acidic, alkali and saline soils and water logging condition. Onions do not thrive in soils having pH below 6.0 because of trace element deficiencies or occasionally, Al or Mn toxicity. It is a temperate crop; however, it can be grown under a wide range of climatic conditions like temperate, tropical and subtropical climate. It prefers a mild weather without the extremes of cold, heat and excessive rainfall. However, onion plant is hardy and in the young stage can withstand freezing temperature also. Short-day onion is grown in the plains in India, which requires 10-12 hrs day length. The onion cultivated in hills is long-day type, which requires 13-14 hrs day length. Lower temperature along with short photoperiod requires for vegetative growth, whereas, relatively higher temperature with longer photoperiod requires for bulb development and maturity. Temperature 13-24^{0}C and 16-25^{0}C, respectively, are the best for vegetative phase and bulb development, while, about 70 % relative humidity requires for good growth. It requires an evenly distributed rainfall of 650- 750 mm during the monsoon period. Areas with low (< 650 mm) or heavy rainfall (>750 mm) are not particularly suitable for rain-fed crop (https://dogr.icar.gov.in).

Nursery Management and Transplanting in *rabi* Onion

Avoid onion mono cropping in heavily fungal diseases infected area. Well drained sandy loam soil rich in organic matter with sufficient land slope to be preferred for onion nursery raising. Water stagnation during

nursery stage favours fungal diseases infection. The land should be prepared well in advance with repeated ploughing and harrowing to obtain a fine tilth. Tillage operation allows birds to kill the exposed pest stages. Seed can be sown on raised bed of 15 cm height or flat nursery bed of about common 2-3 m length and 1-1.5 m width. However, in case availability of drip and sprinkler irrigation, sowing can be taken up on raised beds. Raised bed is mostly recommended.

Apply 500 kg organic manure and 2:1:1 kg NPK 5 guntha^{-1} (500 m^2) before seed sowing as basal dose and 1 kg N 20 days after sowing (DAS). Apply *Trichoderma* 1.25 and *Pseudomonas fluorescens* 2.5-5 kg ha^{-1} with FYM. About 5-6 kg seeds are required to raise seedlings for one hectare. As per experience of some onion growers, if the nursery is managed properly about 3.750-4.375 kg seed is sufficient for 1 hectare. Before sowing, the seeds are to be treated with captan or carbendazim @2-3 g kg^{-1} of seed. Treated and packed seeds do not require treatment again. Two hand weedings are found effective to control the weed population in onion nursery.

In case of weedicide, it is advised to spray pendimethalin at 2 ml L^{-1} of water before onion seed germination followed by hand weeding at 20-25 DAS. Onion seedlings in nursery can be attacked by different insect pests and diseases. So, some control measures are to be taken for getting healthy, pest and diseases free seedlings. Thrips is a major pest of onion. Fipronil 5% SC at 1 ml L^{-1} of water or carbosulfan 25% EC at 2 ml L^{-1} of water can be sprayed to manage thrips population. Sticker is to be used during rainy season. Cloudy weather and dew formation favours fungal diseases like root rot; damping off; wilt; *Cholototrichum* blight etc. Stagnation of water and inadequate drainage favours seedling root rot in nursery.

Root rot can be managed by drenching of copper oxychloride (COC) at 3 g L^{-1} of water. Drenching of metalaxyl 4% + mancozeb 64% at 2 g L^{-1} of water between the rows can manage wilt disease. Integrated approach is to be followed for disease management is given below (Sable and Sonpure, 2023). Soil solarization can be done during summer months in areas were damping off is a major problem.

Nursery Stage

- Maize crop is to be sown as border crop 15 days before onion nursery sowing and transplanting.
- Crop rotation.
- Removal of previous plants residues from the field.
- Application of *Trichoderma viride* @1.25 kg; *Pseudomonas flourescens* 2.5 kg and *Bacillus* 2.5 kg ha^{-1}.
- Sow seeds in 4-5 cm apart on raised beds.
- Seed treatment with captan or carbendazim @2-3 g kg^{-1} of seed.
- Prefer well drained soil.
- In case of continuous rain drenching (L^{-1} of water):
- Metalaxyl 4% + mancozeb 64% @2 g.
- Captan @2 g + potassium humate 1 g.
- Fungicides are to be sprayed (L^{-1} of water):
- At 15-20 day after sowing: Mancozeb 2.5 g.
- At 25-30 day after sowing: Hexaconazole 1 g.
- Water soluble fertilizers and micronutrients spray (L^{-1} of water):
- At 20 DAS: 19:19:19 @2.5 g and 1 g Grade-II (Zn 3%; Fe 2.5%; Mn 1%; Cu 1% & B 0.5%)

Transplanting Stage (TP)
Seedling Root Dipping Treatment

Root dipping in solution: Fungicide carbendazim 1 g and insecticide carbosulfan 2 ml L^{-1} of water (ICAR-DOGR, Rajgurunagar).

After Transplanting Stage (DAT)

- **At 3-5 DAT:** Application of *Trichoderma* @1.25 kg; *Pseudomonas* 2.5 kg; *Bacillus* 2.5 kg ha^{-1}.
- Fungicides and insecticides are to be sprayed L^{-1} of water as per need and infection intensity
- **At 30 DAT:** Mancozeb 2.5 g + fipronil 5%SC 1 ml
- **At 45 DAT:** Propiconazole 25% EC 1 ml + carbosulfan 25% EC 2 ml
- **At 60 DAT:** Azoxystrobin 0.5-1 ml
- **Water soluble fertilizers and micronutrients spray (L^{-1} of water):** 30 and 45 DAT: 19:19:19 @5 g and 2 g Grade IV (Zn 6%; Fe 4%; Mn 1%; Cu 0.5% and B 0.5%).

Transplanting

The transplanting time of *rabi* onion varies from November to December in different *rabi* onion producing states. *Rabi* onion can be transplanted on flat bed whereas, some farmers also prefer transplanting on raised bed for efficient use of fertilizers through drip irrigation. White grub's dirty white coloured 'C'shaped larva enters into the onion main field through well decomposed farm yard manures (FYM) and compost. *Beauveria bassiana* and *Metarhizium anisopliae* (5 kg or L ha^{-1}) can be mixed with neem cake at optimum moisture and applied into the soil before transplanting. These bio-pesticides in liquid form may be applied through drip irrigation or drenching. During the summer make the heaps of FYM/ compost in the field. About 50-55 days old seedlings are to be transplanted in the main field at 15 cm x 10 cm spacing. One third top portion of the seedlings is to be cut at the time of transplanting, if seedlings are tall. Onion seedling's root dipping into solution of fungicide carbendazim 1 g L^{-1} of water and insecticide carbosulfan 2 ml L^{-1} of water is recommended before transplanting to manage pest and diseases up to about one month after transplanting.

Nutrient Management

Fertilizer dosages vary with soil type and its nutrients content, region and variety. Recommended dose of fertilizers (RDF) are to be applied when nutrient content of soil (kg ha^{-1}) is medium. When nutrient content of soil is extremely low, then 50 per cent more RDF to be applied. When nutrient content of soil is low, then 25 per cent more dose of RDF to be applied. At the stage of extremely high soil nutrient content, 50 per cent less dose of RDF to be applied and at high soil nutrient content stage, 25 per cent less dose of RDF is to be applied. Compost/ FYM @25 t ha^{-1} is recommended at the time of final land preparation or vermicompost or poultry manure 7.5 t ha^{-1} can be incorporated one week before transplanting and as an alternative to FYM. Neem cake @250 kg ha^{-1} can be applied in soil before transplanting as preventive measure against nematode infestation. Bio-fertilizers are input containing microorganisms capable of mobilizing and solubilization of nutrients through biological processes. They are less expensive, eco-friendly and sustainable. Research evidences are encourageous towards the integrated use of organic + inorganic + bio-fertilizers which improve the soil productivity and onion yield. Bio-fertilizers can be applied for their positive effect on the soil fertility status and nutrient uptake. Bio-fertilizers like *Azotobacter* 5 kg ha^{-1}; *Phosphorus solubilizing bacteria* (PSB) 5 kg ha^{-1}; *Trichoderma* 1.25 kg ha^{-1} and *Pseudomonas fluorescens* like biofungicided 2.5 kg ha^{-1} can be also

applied with vermicompost or well decomposed farm yard manure after 10 days of enrichment. Bio-fertilizers in liquid form can be preferred for easy application through drip irrigation after 10 days of RDF application. The biological inputs should not be used with chemical fertilizers or any agrochemicals. Experimental results from MPKV., Rahuri suggested that 100:50:50 kg NPK ha^{-1} gave better yield. Basal dose of NPK 50:50:50 kg ha^{-1} is to be applied at the time of transplanting, whereas remaining N 50 kg ha^{-1} to be applied in 2 equal splits at 30 and 45 DAT (Sable and Sonpure, 2023). Apart from macro nutrients, sulphur as a secondary nutrient also required and experiment proved that soil application of sulphur 20 kg along with potash 60 kg ha^{-1} as basal dose enhances onion yield (Sable et al. 2023 and Sable et al. 2024). According to DOGR, Rajgurunagar, soil application of sulphur as an essential secondary nutrient important for onion bulb yield and the pungency. Application of sulphur as basal dose 15 kg ha^{-1} is sufficient for growing onion in soils having sulphur level above 25 kg ha^{-1}, while 30 kg ha^{-1} for soils having sulphur level below 25 kg ha^{-1} for optimum bulb yield. However, sulphur 50 kg ha^{-1} is recommended for long day onion. Recommendations for fertilizer application in onion vary from region to region. For North Gujarat Agro-climatic Zone IV, 100:50:60:20 kg NPKS ha^{-1} is recommended for higher bulb yield in *rabi* onion (Sable et al. 2024).

Within an integrated nutrient management framework experiment results at College of Horticulture, Sardarkrushinagar Dantiwada Agricultual Univeristy, Mehsana, Gujarat (North Gujarat Agro-climatic Zone IV) revealed that Ghanjeevamrut soil application one day before transplanting @6 t ha^{-1} + Jeevamrut @500 L ha^{-1} six drenching at 15 days intervals starting from transplanting until proper bulb development + 50% RDF (62.50:25.00:30.00 NPK kg ha^{-1}) produced the maximum (581.22 q ha^{-1}) bulb yield outperforming the alternative nutrient management practice than 100% RDF (Chaudhary Jayshree, 2026).

Whereas, FYM @15 t or vermicompost or poultry manure 7.5 t, 110:40:60:20-40 NPKS kg ha^{-1} is recommended by DOGR, Rajgurunagar for short day onion in Maharashtra. One third of recommended N and full dose of P and K are to be applied at the time of planting, while remaining two third N is be be applied in two equal splits at 30 and 45 DAT. In order to get potential yield 100 t ha^{-1} in onion, 180:60:70:50 kg NPKS ha^{-1} is recommended for long day onion (https://dogr.icar.gov.in). Sixty days after transplanting, no any nitrogen containing fertilizers should be applied. Role of water-soluble fertilizers and micronutrients in onion nutrition is very important. At 30 and 45 days after transplanting (DAT) 0.5% spray of 19:19:19 and 1 spray of 0.5% 13:00:45 or 00:00:50 during 60-70 DAT enhances crop growth and yield. If soils are deficient in micronutrients and plant shows deficiency symptoms, deficiency can be corrected by spraying with micronutrients mixture Grade-II (Zn 3%; Fe 2.5%; Mn 1%; Cu 1% and B 0.5% @ 0.5%) or Grade IV (Zn 6%; Fe 4%; Mn 1%; Cu 0.5% and B 0.5% @0.2% at 30-45 and 45-60 DAT (Sable and Sonpure, 2023 and Sable et al. 2021, POP, MPKV, Rahuri).

Irrigation and Fertigation

Irrigation requirement of onion depends upon the season, soil type, method of irrigation and age of the crop. In general, onion needs irrigation at the time of transplanting, three days after transplanting and subsequently at 7-10 days interval depending upon the soil moisture. In general, *kharif* crop needs 5-8 irrigations, the late *kharif* crop requires 10-12 and *rabi* crop needs 12-15 irrigations. Onion being a shallow rooted crop, needs frequent light irrigation to maintain optimum soil moisture for proper growth and bulb development. Irrigation needs to be stopped when the crop attains maturity (10-15 days before harvest) and the top starts falling which helps in reducing the rotting during storage. Excess irrigation is always harmful and dry spell followed by irrigation will result in the splitting of the outer scales and also formation of bolters. Water loss with flood irrigation is too high due to conveyance, seepage and percolation losses. Application of fertilizer

through drip (fertigation) is also popular, wherein required quantity of nutrients can be given through soluble fertilizer. Drip irrigation at 100% Pan Evaporation (PE) can improve the marketable bulb yield 15-25% unit area^{-1} as compared to flood irrigation. It saves water about 35-40%, labour 25-30%, respectively. For fertigation transplanting is to be done at a spacing of 15 x 20 cm on a broad bed furrow/ raised bed of 15 cm height and 120 cm top width with 45 cm furrow between two beds. Each broad bed furrow (BBF) should have two drip laterals of size 16 mm at 60 cm distance with emitters at around 30-50 cm distance having discharge capacity 4 L hr^{-1}. Whereas, the distance between two laterals of size 20 mm should be 6 m having discharge capacity 135 L hr^{-1} in case of micro sprinkler. Application of fertilizers @40:40:60 kg NPK ha^{-1} as basal and the remaining 70 kg N in seven splits through drip irrigation is recommended for higher bulb yield with quality produce (https://dogr.icar.gov.in).

Weed Management

As onion plants are closely spaced and shallow rooted crops, it is essential to keep the crop weed free, especially 30-45 days from transplanting. Crop weed competition is recorded higher from transplanting till almost 45 days, it may reduce yield up to 60 per cents. Application of weedicide oxyfluorfen 23.5% EC @1-1.5 ml L^{-1} of water before transplanting or within week after transplanting by using flat nozzle sprayers followed by one hand weeding at 30- 45 DAT, efficiently controls weeds in onion (DOGR/AINRPOG https://dogr.icar.gov.in.). Or spray of oxyfluorfen 23.5% EC at 1 ml L^{-1} of water with quizalofop ethyl 5% EC at 1 ml L^{-1} of water at 25 DAT followed by one hand weeding at 45 DAT can also give good results (Sable et al. 2023; Sable et al. 2021; 2013 and 2014).



Oxyfluorfen @1-1.5 ml L^{-1} water immediately after TP ckecks weed growth



Control (un-weeded) onion plot



Rabi onion bulbs production through integrated weed management practice



Rabi onion bulbs production from un-weeded (control) plot

Disease and Pest Management

Onion crop can be attacked by different insect pests and diseases. Thrips (*Thrips tabaci*), onion maggot/ onion fly (*Delia antique*) etc. are major pests of onion. Diseases like damping off (*Fusarium oxysporum* f.sp.epae, *Pythium* sp.; *Sclerotium rolfsii*); wilt; *Cholototrichum* blight/ twister (*Colletotrichum gleosporiodes*); purple blotch **(***Alternaria porri***)**; stemphyllium leaf blight **(***Stemphylium vesicarium***)**; basal rot/ plate rot (*Fusarium oxysporum* f.sp.epae); white rot/sclerotium rot (*Sclerotium rolfsi*); neck rot (*Botrytis allii*); bacterial brown rot (*Pseudomonas aeruginosa*); black moult (*Aspergillus niger*); irish yellow spot virus (IYSV); onion yellow dwarf virus (OYDV) etc. are severe diseases of onion. Thrips; damping off; wilt and *Cholototrichum* blight (twister) management practices are explained in nursery stage, at transplanting stage and after transplanting stage management part. Experiemntal result revealed that spray of carbendazim 12% + mancozeb 63% (0.25%) or propiconazole 25 EC (0.1%) or mixture of *Trichoderma* + *Pseudomonas* (1%) three times at an interval of 15 day minimizes the incidence of twister disease effectively and avoids the yield loss (Manthesha et al. 2022). Suitable plant protection measures can be taken to minimize yield losses, while, adapting plant ptotection measures some points need to be considered viz. start foliar sprays of pesticide from 30 DAT or as soon as pest and disease appears in the field; interval 10-15 days depending upon the intensity of pest and disease; spreader to be added @0.5% while spraying and avoid repeated application of pesticides belonging to the same group.

Management of Damping Off

Damping off can be managed by adapting management practices viz. transplanting of seedlings on the raised bed; seed treatment with thiram or captan @0.3%; drenching the nursery beds by captan or thiram @0.2% or carbendazim @0.1% or copper oxychloride @0.3%. Soil solarization during summer months is also recommended.

Management of Purple Blotch

Current management strategies rely on fungicide sprays. Foliar spray of the fungicides is recommended by DOGR, Rajgurunagar viz. mancozeb @0.25% or tricyclazole @0.1% or hexaconazole @0.1% or propiconazole@0.1% at 10-15 days intervals from 30 DAT or as soon as disease appearance. Spray fungicides with sticker.

Above economic threshold level, foliar spray of Azoxystrobin 18.2 + Difenoconazole 11.4% SC @1 ml or Tebuconazole 50% + Trifloxystrobin 25% (w/w) @0.6 ml or Metiram 55% + Pyraclostrobin 5% WG @1 g L^{-1} of water after 60 DAT is recommended.

Management of *stemphyllium* Leaf Blight

Foliar spray of mancozeb @0.25% or tricyclazole @0.1% or hexaconazole @0.1% or propiconazole @0.1% at 10-15 days interval from 30 DAT or as soon as disease appearance. Above economic threshold level follow spray as given for management of purple blotch (ICAR-DOGR, Rajgurunagar).



Purple blotch



Stemphyllium blight

Thrips and Blight Management

If thrips infestation and blight infection observes at a time, it can be managed by spraying mancozeb 2.5 g + fipronil 1 ml L^{-1} of water at appearance of pest and disease; propiconazole 1 ml + carbosulfan 2 ml L^{-1} of water at 45 DAT and copper oxychloride 2.5 g + profenofos 1 ml L^{-1} of water along with sticker at 60 DAT as per pest and disease intensity (ICAR-DOGR, Rajgurunagar, Sable et al., 2023).

Onion Yellow Dwarf Virus (OYDV) Management

For effective management of OYDV integrated pest and disease management strategies should be followed viz. selection of OYDV resistant variety, aphid management as aphis is the vector, spray of insecticides like profenofos @0.1% or carbosulfan @0.2% or fipronil @0.1% for aphid management. Above economic threshold level follow spray as given for management of purple blotch.

Management of Iris Yellow Spot Disease

Iris yellow spot disease (virus) transmitted through onion thrips and can be managed by adapting thrips management practices, but thrips control alone is not sufficient to economically control the disease. For its effective management, IPDM strategies should be followed viz. selection of planting material free from thrips and iris yellow spot virus; three years or longer rotation between onion crops; elimination of volunteers and timely weed management.

Onion Maggot Management

For its effective management, integrated pest management strategies should be followed viz. avoid successive planting of onion in the same field and follow crop rotation; use of well decomposed FYM; soils that are rich in un-decomposed matter should be avoided; avoid close planting of onions to reduce movement of maggots in the nearby areas; drenching of the chlorpyrifos with irrigation at 1.6- 2 L $acre^{-1}$ is to be done before transplanting or when infestation starts to appear and after hand weeding fipronil 80% WG can be applied in the soil at 1 kg $acre^{-1}$ followed by irrigation.

Harvesting, Cutting and Bulb Yield

Duration of *rabi* onion crop is varied by several factors like variety, soil, climate etc. Generally, a bulb matures in about 110-130 DAT and harvested one week after 50-70 per cent neck fall. For sale as, dried bulbs or for storage onions are ready to harvest when the tops start to turn yellow and die. The most important thing needs to be remembered at bulbs harvesting that outer protective layer should not be damaged. Disease infection and dryness of bulbs may be occurred due to outer layer damages. The leaves are to be cut leaving about 2-2.5 cm tops above the bulb after complete drying. The average yields of 25-35 t ha^{-1} can be obtained from *rabi* onion crop (Sable and Sonpure, 2023).

Curing and Storage

Generally, a farmer prefers to store *rabi* onion bulb produce when price is less at the harvest time. Suitable protection measure requires for minimizing yield losses during staorage. Blue or black mould disease incidence in storage can be minimized by pre-harvest spray of carbendazim @1 g L^{-1} of water at 30 and 10 days before crop harvest. Diseases like bacterial brown rot; plate rot; neck rot; black mould etc. can spread from field to storage so some precautions are to be taken for long time storage of onion bulbs. When bulbs are completely dried, cut off the necks to about 2-3 cm long because many diseases enter into bulbs through neck. Before cutting field curing for 3-5 days should be done covering the bulbs with foliage. Bulbs intended for storage need to be cured in thin layer under shade for 15 days. Bulbs harvested during rain should not be preferred for storage. While, preparing onion storage unit, some points need to be considered viz. storage structure should have at proper height from the bottom; away from wet land and at well aeration location. Humidity 65- 70 per cent and temperature 25- 30^0C are to be maintained inside the storage stricture for long time bulb storage. Before filling storage structure with onion bulbs, empty structure surfaces should be sprayed with carbendazim @2 g L^{-1} of water. Bulbs are to be filled up to height 3-4 feet in storage structure. The length of onion structure of double chawl (double chawl/ double row/ double compartment kanda chawl) should be more than 40 feet. Double chawl structure should be raised along the wind direction and single chawl across the wind direction. Double chawl bottom and side ventilated strong structure or single chawl low-cost onion stracture is recommended by DOGR, Rajgurungar.

Multiplier Onion/ Aggregatum Onion

(*Allium cepa* var. *aggregatum*, 2n = 2x = 16)

This is used mainly for seasoning of curries. Unlinke common onion, it is propagated through bulblets via daughter bulbs. Unlike common onion, multiplier onion comes up well under tropical condition with sufficient soil moisture. Red loam to black soil with pH 6-7 having good drainage capicity is highly suited for multiplier onion cultivation. It requires sufficient soil moisture during its growing period but heavy rain during germination and bulbing is deleteriouis for the crop. Varieties viz. Agrifound Red; CO 1; CO 2; CO 3; CO 4; Arka Ujjwal and MDU 1 are used to produce small sets. Variety CO 5 of multiplier type onion flower free commonly cultivated.

Bulblets Preparation (Planting Material)

This is the most common method practiced for irrigated crop as it results in high yield and large size bulbs. In plains, seeds are sown during October-November for a *rabi* crop, while from March to June in hills. The

nursery area should be irrigated lightly and covered with 200-gauge transparent white polythene during March to May for about 6-7 weeks known as soil solarization, where soil temperature rises up to 50°C. After 6-7 weeks, polythene sheet cover is to be removed and prepare the nursery beds. For raising nursery, raised bed of about 2-3 m length; 1-1.5 m width and 15-20 cm height is to be prepared. The distance between 2 beds should be 30 to 45 cm. Well decomposed FYM 500 kg and 2:1:1 kg NPK 5 guntha^{-1} before seed sowing and 1 kg N 20 DAS to be applied. *Trichoderma* 1.25 and *Pseudomonas fluorescens* 2.5- 5 kg; *Beauveria bassiana* and *Metarhizium anisopliae* 5 kg or L; bio-fertilizers like *Azotobacter* 5 kg; *Phosphorus solubilizing bacteria* (PSB) 5 kg ha^{-1} with FYM or vermicompost can be applied (generally 7- 10 days after basal RDF application). To produce small setts, seed @10–12 g m^{-2} is recommended. For planting of one-hectare area, 08–12 kg onion seed is sufficient for setts production. The best time of seed sowing is from mid-January to first week of February in which maximum quantity sets of desirable size (1.5 cm to 2.5 cm) are obtained. Ratio between nursery area and main field is about 1:20. The ideal planting material will be achieved in around 60 DAS; within this period desired size of setts 1.5 to 2.5 cm will be attained. When folliage dry up, harvesting to be done alongwith the tops. The selected sets of size 1.5- 2.5 cm are to be stored by hanging method or in plastic crates in properly ventilated room or godown. Generally, 1 t of bulblets will be required for planting on 1 ha area, while 2.6 t ha^{-1} bulblets will be required of 1.5 – 2 cm acceptable size.

Planting Method of Setts

The medium sized bulbs to be planted on raised beds or both sides (solders) of ridges in BBF system for better bulb development. It can be planted in ridges and furrows of 45 cm size. Bulblets are to be planted on both the sides of the ridges at 10 cm apart. Bulbs are planted during April – May and October – November at spacing 10 cm x 10 cm on raised bed followed by irrigation, immediately to maintain uniform moisture level. Dipping of bulblets in the solution of carbendazim @0.1% and carbosulfan @0.2% before planting helps in better establishment of bulblets (Gupta, et al. 2023). Planting of oversized bulblets increases bolting and reduces the qulity of the produce.

Nutrient Management

According to TNAU, generally application of FYM 25 t; *Azospirillum* 2 kg and PSB 2 kg and 60:60:30 kg NPK ha^{-1} have been found effective for higher bulb production. Half quantity of recommended N and full dose of P_2O_5 and K_2O to be applied at the time of planting as a basal, while remaining half N to be applied on 30 DAT. Application of 100:50:60:30 kg NPKS ha^{-1} have been found effective for higher bulb production. Half quantity of nitrogen and full quantity of phosphorus; potash and sulphure to be applied at the time of bulblets planting, whereas the remaining half dose of nitrogen to be applied in 2 equal doses as top dressing in standing crop at 30 and 45 DAT (Gupta, et al. 2023). In addition to fertilizer application, spray of 19:19:19 @0.5% at 15 and 30 DAP followed by spray of 13:00:45 @0.5- 1.0% at 40 and 50 DAP gives higher bulb yields. Like onion, application of micronutrients is beneficial in improving the quality of bulbs.

Harvest and Yield

Crop will be ready for harvest, when bulbs are fully developed, colour of bulbs also develop and the tops of the leaves start yellowing. The irrigation should be stopped before harvesting. Generally, bulb yield 12-16 t ha^{-1} is expected and bulbs matures in 70 to 90 days, while 18 t ha^{-1} bulb yield is obtained from variety CO 5 in 90 days. Bulb yields of 25–30 t ha^{-1} can be realized from *kharif* crop under proper crop management (Gupta, et al. 2023). The crop grown by setts attains early maturing (65 – 72 days) which is 30 – 50 days in

advance as compared to seedling planted crop (90 – 100 days). Spray of carbendazim @1000 ppm 30 days before harvest have been found effective for extending the shelf life of bulbs. Harvesting is to be done by pulling out plants when tops are drooping but still green. Cleaning and curing of the bulbs (4 days in shade) is important for better shelf life.

Plant Protection for Multiplier Onion

Similar to that of onion.

Garlic (*Allium sativum* L.)

Garlic is one of the important bulb crops among all bulbous crops grown and used as a spice or a condiment. The aroma in garlic is due to volatile organosulfur compound 'Allicin' that makes it popular in daily cooking in Indian household. The antibacterial action by virtue of *allicin* has been found to have potential even in organic farming for treatment of plant diseases (Malik et al. 2017). Uninjured garlic bulbs contain *alliin*, a colourless, odourless and water-soluble amino acids. On crushing the garlic bulbs, the enzyme allinase comes in contact with *alliin* and causes its breakdown into a sulphur containing product *allicin* which is the antibacterial substance of garlic and has typical odour of fresh garlic. The *alliin* of garlic contains an allyl radical from which allyl products are develoled. Garlic contains about 0.1- 0.4 per cent essential oil. The chief constituents of oil are diallyl disulfide (60%); diallyl trisulfide (20%); allyl propyl disulfide (6%); a small quantity of diethyl disulfide and probably diallyle polysulfide. Diallyle disulfide posseses the true garlic odour (Singh and Pal, 2022 and Alekar et al. 2020). Garlic has been cultivated for thousands of years. It is the most ancient cultivated vegetables giving pungency to the genus *Allium*. In India, garlic is commercially cultivated throughout the country. But the long day garlic is cultivated only in temperate region especially in Jammu and Kashmir; Himachal Pradesh; Uttarakhand. This type requires long photoperiod (13+ hrs/ 13-14 hrs) with warm temperature (20-25°C) for bulbing (Malik et al. 2017 and Khade et al. 2017). In temperate India, the planting time for long day garlic falls around September-October. The increase in day length from around February following the decline in snowfall and rise in temperature till the month of May is congenial for bulbing and bulb development.

Origin and Taxonomy

Its origin is cental Asia and Mediterranean region. *A. longicuspis* Rgl. is believed to be its wild ancestor. Garlic belongs to family Alliaceae, genes- *Allium* and spp. *sativum* L. Its chromosome number (2n=2x) is 16. It is perennial species, producing a much-divided bulb, consisting of several cloves, covered by a thin white skin. It differs from onion in that the leaf base does not store food, but metric as dry scales enclosing the cloves. The cloves are well developed axillary buds within the thin foliage leaves. It is sexually sterile diploid. After domestication, garlic is exclusively propagated by vegetative methods i.e. by cloves and in some cases inflorescence bulbils (Singh and Pal, 2022).

Crop Improvement

In India, exploration and clonal selection have been the most widely implemented breeding tools because garlic having apomictic nature. The DOGR, Rajgurunagar, ICAR- VPKAS, Almora; CITH, Srinagar; SAU's like MPKV, Rahuri and NHRDF, New Delhi have been involved in developing and identifing clones suitable for different day length conditions of the country after rigorous evaluation through All India Network

Research Project on Onion and Garlic (AINRPOG) and AICRP on (Vegetable crops). In J and K, the ICAR-CITH, Srinagar has conducted several explorations and identified 73 cloves of garlic from different areas of Kashmir on the basis of phenotypic variability are being evaluated for higher pest and diseases resistance/ tolerance as well as yield attributing characters. These clones have considerably greater marketable yield potential as compared to their short day and intermediate types. The marketable yield during 2015-16 ranged from 6.6 - 44.15 t ha^{-1} with a mean of 23.70 t ha^{-1}. When compared with popular short and intermediate garlic clones grown elsewhere in India, these collections provide great promise in escalating India's productivity. Two high yielding cultivars viz. VL Garlic-1 and VL Lahsun-2 has released by ICAR- VPKAS, Almora. The ICAR- DOGR, Rajgurunagar is also contributing to the long day germplasm collected from different parts of the country including states of Sikkim; West Bengal and abroad, which are being evaluated under long day conditions of Kashmir valley of which four lines are found promising for long day conditions with quality and high yield. DOGR, Rajgurunagar has developed commercial rapid detection RTPCR kits for Iris Yellow Spot Virus and Onion Yellow Dwarf Virus useful for rapid and high through put detection of diseases in garlic crop samples (Malik et al. 2017).

Seasons

State (s)	Season	Time of planting	Time of harvesting
Chhattisgarh, Gujarat, M.P. and M.S.	*Rabi*	September-November	March
Tamil Nadu (Ooty)	*Kharif*	June-July	October-November
	Rabi	October-November	March-April
Karnataka	*Kharif*	June-July	October-November
	Rabi	September-October	March
Andhra Pradesh	*Rabi*	September-October	March
Bihar, Haryana, Punjab, Rajasthan, UP and Uttarkhand	*Rabi*	October-November	March-April
Odisha and West Bengal	*Rabi*	October-November	March
Hilly areas (Long day types)	*Rabi*	September	May

Source: https://dogr.icar.gov.in

Varieties

Brief descriptions of varieties are given below.

Variety	Orgnization	Colour	Recommeneded for area	Duration (Days)	Yield (t ha^{-1})
Bhima Purple (SD)	ICAR-DOGR	Purple	AP; Bihar; Delhi; Haryana; Karnataka; MS; Punjab and UP.	120-135	6-7
Bhima Omkar (SD)	ICAR-DOGR	White	Delhi; Gujarat; Haryana and Rajasthan.	120-135	8-14
Agrifound White (G 41) (SD)	NHRDF	White	MP. and MS.	130-135	12-14
Yamuna Safed (G 1) (SD)	NHRDF	White	All India	120-130	15-17

Yamuna Safed 2 (G 50) (SD)	NHRDF	White	Northern India	120-130	15-20
Yamuna Safed 3 (G-282) (SD)	NHRDF	Creamy white	Chhattisgarh; Gujarat; Haryna; MP; MS; Punjab; Rajasthan and UP	120-130	17-20
Yamuna Safed 4 (G-323) (SD)	NHRDF	White	North and central India	165-175	16-17
Yamuna Safed 5 (G-189) (SD)	NHRDF	White	Andaman and Nicobar Island; Arunachal Pradesh; Bihar; Delhi Gujarat; Haryana; Jharkhand; Manipur; Meghalaya; Mizoram; Nagaland; Punjab; Rajasthan; Sikkim; Tarai region of UP; Tripura and Uttarakhand.	150-160	17-18
Godavari (SD)	MPKV	Purple	Maharashtra	140-145	10-11
Shweta (SD)	MPKV	White	Maharashtra	130-135	10-11
Phule Baswant (SD)	MPKV	White	Madhya Pradesh and Maharashtra	135-140	10.-11
Phule Nilima (Sel-10-3)	MPKV	Purple	Maharashtra	-	-
GG 4 (SD)	JAU	White	Gujarat and Maharashtra	130-140	8-10
GG-2 (SD)	JAU	White	Gujarat	-	7. 50
Gujarat Anand Garlic 6 (GAG 6)	AAU	Purple	Gujarat	-	7.0
AAS-2	UHS	Pinkish	Karnatak	96 -110	
Ooty 1 (ID)	TNAU	White	Tamil Nadu	120-130	15-17
VL Garlic 1 (LD)	ICAR-VPKAS	White	Bihar; HP; J & K; Punjab; Uttarakhand and UP	180-190	Hills: 14-15 Plains: 9-10
VL Lahsun 2 (LD)	ICAR-VPKAS	White	HP, J & K and Uttarakhand	190-200	Mid hills: 14-16 Above mid hills: 24-26
Agrifound Parvati (LD)	NHRDF	Purple	Hills of HP; Uttarakhand; J & Kand high altitudes of North eastern states like Sikkim etc.	165-175	17-18
Agrifound Parvati 2 (G 408) (LD)	NHRDF	White	Hills of HP; Uttarakhand; J & K and high altitudes of North eastern states like Sikkim *etc*.	165-175	17-22

CITH-G-1 (LD)	ICAR-CITH, Srinagar	Violet strip	J & K; Uttarkhand; H.P.	210-245	25-35
PDKV-Purna (AKG 07)	Dr. PDKV, Akola (MS)	-	Maharashtra	-	-
CITH Jambo	ICAR-CITH, J and K, Srinagar	-	J and K	-	-

*SD= Short day type; ID= Intermediate day and LD= Long day type

Source: NHRDF, ICAR-DOGR and SAU Portal



Garlic crop

Soil and Climate

Garlic can be grown in all types of soils. However, fertile loamy soils with pH 6.0 – 8.0; EC 3.9 dS /m; good drainage capacity; water holding capacity and containing organic matter in sufficient amount is the best. Like onions, garlic are very much sensitive to highly acidic; alkali; saline soils and water logging condition. It can be grown under a wide range of climatic conditions, but it cannot tolerate too hot and too cold temperatures. It prefers cool and moist climate during vegetative growth and bulb development stages, while, warm dry weather during maturity. Like onion, cool climate during garlic growing periods reflects into higher yield as compared to warm conditions. In garlic, subsequent bulbing hastens when young plants exposures to 20°C or lower temperature for 1-2 months, while, plants that are not exposed to such climatic conditions may reflects into failure of bulb production or smaller bulb production. The ideal growth temperature for garlic is 13 to 24°C, however longer exposure to low temperature may produce bulbils in the axils of the leaves, which reduce the bulb yield. Short day garlic requires 10-12 hrs day length for bulbing, while, long-day garlic requires 13-14 hrs day length (https://dogr.icar.gov.in).

Propagation

Garlic is propagated vegetatively by cloves. Bulbils produced in some varierties are also used as planting material. Individual clove from seed garlic bulbs is to be separated (Not long before planting) by twisting off

the outer skins and take the cloves apart without breaking the basal plate of the cloves, as broken cloves are not used for planting. Cloves of 8- 10 mm daimetre with more than 1.5 -2 g weight are to be selected for planting, while small, diseased and damaged cloves should not be used for planting. Big sized cloves from outer side of the bulbs are to be selected, while, long, slender cloves present in the centre should not be used for planting because such cloves give poorly developed bulbs. Incidence of fungal diseases during establishment can be minimized by dipping cloves in carbendazim solution (0.1%), just before planting. For planting in one-hectare area about 500-600 kg cloves are required (Alekar et al. 2020 and Singh et al. 2016). Cloves should be planted vertically 2 cm below soil surface at 15 cm x 10 cm spacing (https://dogr.icar.gov.in).

Nutrient Management

According to ICAR- DOGR, bio-fertilizers like *Azospirillum*/ *Azotobacter* 5 kg ha^{-1}; *Phosphorus solubilizing bacteria* (PSB) 5 kg ha^{-1} can be applied before planting through 100-200 kg 50% moisturized well rotten FYM (After overnight enrichment). Farm yard manure 10 t; 100 kg N;50 kg P_2O_5 and 50 kg K_2O ha^{-1} gives higher yield in Jammu and Kashmir; Uttarakhand; Himachal Pradesh condition (Singh et al. 2016). Farm yard manure is to be applied at the time of land preparation. Half dose of nitrogen along with full dose of phosphorus and potassium are to be applied as basal dose at time of planting; while remaining half nitrogen is to be applied at time of bulb initiation. Sulphur 30 kg ha^{-1} need to be applied as basal dose (Dubey and Gupta, 2021). Application of 100:50:50:50 kg NPKS along with 20 t FYM ha^{-1} is recommended for Haryana; Uttarkhand and Uttar Pradesh region (Khade et al. 2017). One third of nitrogen and full recommended dose of phosphorus; potassium and sulphur should be applied as basal at the time of planting, while remaining two third of nitrogen should be applied in two equal splits at 30 and 45 days after planting. Based on the field experiments carried out through All India Network Research Project on Onion and Garlic at different locations, application of 75:40:40:40 kg NPKS ha^{-1}along with FYM 15 t or 7.5 t poultry manure or 7.5 t ha^{-1} vermicompost recommended for Bihar; Chhattisgarh; Gujarat; Karnataka; Madhya Pradesh; Maharashtra; Odisha; Rajasthan; Tamil Nadu region. Experimental results from MPKV., Rahuri suggested that 100:50:50 kg NPK ha^{-1} gave better bulb yield. Basal dose of NPKS 50:50:50:40-50 kg ha^{-1} is to be applied at the time of planting, whereas remaining N 50 kg ha^{-1} to be applied in 3 equal splits at 30; 45 and 60 DAP. Role of water-soluble fertilizers and micronutrients in garlic nutrition is very important. At 30; 45 and 60 DAP 0.5% spray of 19:19:19 enhances crop growth and garlic bulb yield. Micrunutrients viz. zinc; boron and secondary nutrient sulphur also helps to improve garlic bulb yield as well as quality. Like onion, micronutrient deficiency can be corrected by spraying micronutrient mixture (Fe: 2.5%; Zn: 0.3%; Mn: 1%; Cu: 1.0%; B: 0.2%) at 45 and 60 DAP along with application of FYM @ 15 t ha^{-1} as a basal zinc and boron deficiency can be corrected by soil application of ZnSO @10 kg ha^{-1} as basal in areas having zinc deficiency and borax @10 kg ha^{-1} for areas having boron deficiency.

Weed Management

Like onion, higher crop weed competition is observed in garlic also, which reduces yield. Application of oxyflurofen 23.5% EC 1.5 -2.0 ml L^{-1} or pendimethalin 30% EC 3.5-4 ml L^{-1} before or at the time of planting + one hand weeding at 40-60 DAP shows higher weed control efficiency (Dubey and Gupta, 2021; Singh et al. 2016; Khade et al. 2017).

Irrigation

Garlic requires frequent but light irrigation because its roots are very shallow. Irrigation varies accordingly climate and soil type. It is very sensitive to moisture stress particularly during bulb initiation and bulb development. Irrigation requirs after planting immediately, while irrigations at an interval of 7-10 days as per soil moisture level. *Kharif* crop requires about 5-8 irrigations, while, *rabi* crop requires 12-13 irrigations. Irrigation needs to be stopped 10-15 days before harvest, when the crop attains maturity. Water stagnation is always harmful and dry spell followed by irrigation will reflect into the splitting of the outer scales of garlic. Waterlogged conditions should be avoided at all stages because it favours disease infections such as basal rot and purple blotch. Similarly, continuous irrigation towards maturity reflects into secondary rooting which produces new sprouts and such bulbs cannot be stored for long time (Alekar et al. 2020).

Micro-irrigation (Modern Micro-Irrigation Techniques)

Drip as well as sprinkler irrigations save water; fertilizers and enhances bulb yield 15-25% as compared to flood irrigation in case of drip. For drip irrigation, seed cloves are to be planted at a spacing 15 x 10 cm on raised bed/ broad bed furrow having height 15 cm and top width 120 cm with 45 cm furrow between two beds. Each raised bed should have two 16 mm size drip laterals at 60 cm distance with emitters at around 30-50 cm distance having discharge capacity 4 L hr^{-1}. While, in case of sprinklers, the distance between two 20 mm size laterals should be 6 m having a discharge capacity of 135 L hr^{-1} (https://dogr.icar.gov.in).

Fertigation

Application of nitrogenous fertilizers through drip irrigation reduces nitrogen losses by leaching. Water soluble fertilizers can be applied at root zone directly as per crop requirement thereby improving fertilizer use efficiency. Nitrogen use efficiency can be increased by applying 30 kg N ha^{-1} in soil at the time of planting and the remaining 70 kg N ha^{-1} in seven splits equally at weekly interval up to 60 DAP through drip irrigation (https://dogr.icar.gov.in).

Harvesting and Yield

Harvesting starts when the leaf tops start to dry, discolour and bend towards the ground. Another indication of bulb maturity is the reduced thickness of the sheath leaves surrounding the bulb. Generally, garlic matures in 130-160 days depending upon the cultivar, location and season. Early harvest results in bulbs which are immature and tend to shrivel when cured, while late harvest may result in bulbs which have stained and have partially decayed wrapper leaves and exposed cloves. Garlic bulbs along with top may be cured/ dried in the field for two to three days after harvesting to increase storage life by minimizing microbial and fungal infection and water loss during storage. Researches conducted at MPKV., Rahuri (MS.) evidenced that the average crop yield was ranged 9- 10 t ha^{-1}.

Storage

Garlic is mainly a *rabi* crop harvested during March and is required throughout the year for consumption. Hence, garlic bulbs should be stored properly to meet the supply year-round. Well cured (dried neck and outer skins); clean bulbs firm to the touch can be stored for 5-6 months at ambient temperature in ventilated storage structures, but with low relative humidity (<70%). Bulbs should be graded before storage and 20-25

plants tied in bundles along with tops. The tops should be divided in three segments and interwoven tightly. Such bundles are kept in upright position in shade for curing for 15-20 days and hang them in dry and well-ventilated area or use forced air to dry bulbs. If the large quantity of bulbs needs to be stored, these should be arranged in 4 feet diameter circle and to a height of 3 feet. The heap diameter should be reduced gradually from 4 feet bottom to 3 feet at top while arranging the bulbs. There should be a gap between two heaps for good ventilation.

High humidity in the stores favours mould growth and rooting. Mould growth can also be a problem if the bulbs have not been well cured before storing. During storage, bulbs will eventually become soft, spongy and shrivelled due to water loss. Excessive exposure of bulbs to direct sunlight should be avoided as it causes sloughing due to excessive shrinkage.

For long-term storage, garlic can be best stored in cold store at temperatures -1°C to 0°C with low relative humidity (60-70%). Application of excess nitrogen and irrigation 15-20 days before harvesting favours sprouting of bulbs in the field. Early planting of garlic also causes sprouting. This can be prevented by optimum supply of nitrogen and stopping irrigation about 15-20 days before planting. Irradiation with 2-6 krad of cobalt 60 gamma rays has been recommended for controlling sprouting in storage. The irradiation given to bulbs within 8 weeks of harvesting (before sprout initiation) can inhibit sprouting effectively, reduce weight loss and prolong storage life for about one year. Doses higher than 10 Kr reduce diallyl disulfide content which gives typical garlic flavour. For seed garlic, pre-harvest spraying with 0.1% carbendazim and disinfection of stores before storage reduce post-harvest losses particularly decay loss (https://dogr.icar.gov.in).

Plant Protection

Similar to that of onion.

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