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Onion (*Allium cepa* L.): Breeding for quality traits and export

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Abstract

Among *Allium* crops, onion and garlic are exclusively grown and consumed in the form of fresh as well as processed products. In India, onion and garlic are integral part of daily diet in every household, grown under three crop seasons i.e. kharif, late kharif and rabi. The Rabi crop occupies more than 50% of production. India is the 2nd largest producer of onion and garlic after China. Development of varieties having attractive bulbs with uniform in size, shape, colour and uniform maturity, high dry matter and long storage life. As well as additional desirable features like intact and attractive skins, thick leaf scales as uniform rings, single centred bulb, thin neck, and resistant to premature bolting, diseases and pests. Each of these characteristics is genetically inherited but can be modified by environmental and cultural practices. However, several organizations worked/released many varieties and hybrids as well as production technologies, which increases area, production, productivity and export of onion.

Introduction

India is the 2nd largest producer of onion and garlic after China. Total area under onion was over 14.31 lakh ha with a total production of 26 lakh tons and productivity 18.23 t/ha during 2019-20. In the past two decades, production of onion in India has increased more than four times, and 13 lakh tons onion exported with the worth of Rs 2017 crores. Because of pungent and tingling taste of Indian onion, it is being exported to Middle East and South East Asian countries, namely Bangladesh, Malaysia, Sri Lanka, UAE and Nepal. The red, pink and white onions grown under short day conditions of India are also popular in European countries (DAC&FW 2020).

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Onion is highly cross pollinated crop; thus natural variability is created constantly due to its out breeding nature. Therefore, adoption and acclimatization of onion has undergone continuous selection to suit as per climate and market demands. Systematic breeding programme was started as early as 1960 at Pimpalgaon Baswant, Nasik, Maharashtra, and later at IARI, New Delhi. The programme was further strengthened under coordinated project through SAUs and ICAR institutes. As a result, a number of varieties of common onion and multiplier onion have been developed by introduction, mass selection, selfing and massing, hybridization and heterosis breeding (Table 1). Major breeding objectives are: High bulb yield; superior bulb quality traits such as uniform bulb size, shape, colour, pungency, firmness and dormancy; high total soluble solids content for dehydration industry; skin color retention and high dry matter; resistance to diseases such as purple blotch, basal rot, *Stemphyllium* blight, anthracnose, pink root rot and bacterial rot; resistance to insect pests mainly thrips, nematodes and bulb maggots; resistance to abiotic stresses namely moisture stress, high temperature, salinity and alkalinity; development of high yielding varieties capable of producing good seed yield; development of disease resistant F_1 hybrids with superior quality bulbs; and development of varieties suitable for export market.

Since onion is a highly cross pollinated crop and biennial in nature, it takes almost 12-14 years to purify or develop a new variety or hybrid, which is cumbersome. Most of the breeding methods suited to cross pollinated crops generally employed for the genetic improvement of onion. Products of these improvement strategies are open pollinated varieties or hybrids. Various breeding methods were followed in onion improvement for quality production and export and most adopted methods are mass selection, recurrent selection, pedigree selection, single bulb selection followed by mass selection, heterosis breeding, mutation breeding, family selection, pedigree

Table 1: List of different onion varieties released worldwide using population improvement methods

S. No.	Variety released	Improvement Method Used	Reference
1	Improvement of ancient Russian variety 'Spasskii'	Mass selection and Intravarietal recurrent hybridization	Efimochkina (1970)
2	Yalova 1, Yalova 3 and Yalova 12	Mass selection in Marmara population and Single plant selection in Thrace population.	Akgun (1970)
3	N– 53	Mass Selection (Collection from Nashik, Maharashtra)	MPKV, Rahuri, 1975
4	Punjab Selection	Mass Selection in indigenous material (Collection from Punjab)	PAU, Ludhiana, 1975
5	Pusa White Flat	Mass Selection (Local Collection)	IARI, New Delhi, 1975
6	Pusa White Round	Mass Selection Local collection (106)	IARI, New Delhi, 1975
7	Co 2	Mass Selection (Collection from Tamil Nadu)	TNAU, Coimbatore, 1978
8	Punjab – 48	Mass Selection (Collection from Punjab)	PAU, Ludhiana, 1978
9	Pusa Ratnar	Mass Selection (Selection from Red Granex from USA)	IARI, New Delhi, 1978
10	Pusa Red	Mass Selection (Local Collection)	IARI, New Delhi, 1978
11	Co 3	Mass Selection (Collection from Tamil Nadu)	TNAU, Coimbatore, 1982
12	Kalyanpur Red Round	Mass Selection (Collection from U P)	CSUAT, Kanpur, 1983
13	Arka Pragati	Mass Selection (Collection from Nashik, Maharashtra)	IIHR, Bangalore, 1984
14	N–2–4–1	Mass Selection (Collection from Pune, Maharashtra)	MPKV, Rahuri, 1985
15	Arka Niketan	Mass Selection (Mass selection from a local collection IIHR – 153)	IIHR, Bangalore, 1987
16	Agrifound Dark Red	Mass Selection (Collection from Nashik, Maharashtra)	NHRDF, Nashik, 1987
17	Pusa Madhavi	Mass Selection (Collection from Muzaffarnagar, U P)	IARI, New Delhi, 1987
18	'Dorata di Parma' resistant for *F. oxysporum* f. sp. *cepae* Snyd. et Hans.	Mass and recurrent selection	Fantino and Schiavi (1987)
19	Arka Kalyan (Sel-14)	Mass Selection (Mass selection from a local collection IIHR – 145)	IIHR, Bangalore, 1987
20	Baswant – 780	Mass Selection (Collection from Pimpalgaon, Maharashtra)	MPKV, Rahuri, 1989
21	VL Piaz 3	3 cycles of Mass selection after F_2 of cross 'In-13 x L-43'	Mani et al. (1999)
22	Screening and analysis of components of white shaft weight	Maternal pedigree selection in male sterile-plants and male-fertile plants (MPSMS and MPSMF)	Zhaoshui et al. (1995)
23	Composto IPA-6 and Belem IPA-9	Breeding program tolerant to *C. gloeosporioides* and T. tabaci, good post-harvesting conservation qualities	De Franca and Candeia (1997)
24	Cobriza INTA	Mass Selection from Valenciana type onions	Galmarini et al. (2001)
25	Navideña INTA	Mass Selection from Torrentina local population	Galmarini et al. (2001)
26	Antártica INTA	Mass Selection from Valenciana type onions	Galmarini et al. (2001)
27	NuMex Chaco' Onion	Recurrent Selection	Cramer and Corgan (2001a)
28	NuMex Snowball' Onion	Recurrent Selection	Cramer and Corgan (2001b)
29	NuMex Arthur' Onion	Recurrent Selection	Wall and Corgan (2002)
30	Congregation of desirable genes in Gholy – Ghesseh Local Onion	Mass Selection	Javad et al. (2004)
31	Purifying the popular land variety "Abu Ferewa"	Phenotypic recurrent mass selection and Inbreeding followed by bulking	Bakheet (2008)
32	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)
33	Arka Pitambhar	Pedigree selection from the cross U.D. 102 x IIHR-396	IIHR, Bangalore http://www.iihr.res.in/frmVarities.aspx
34	Bhima Super	Rigorous mass selection for single centeredness & bulb shape	Lawande et al. (2007, 2011a)
35	Bhima Red & Bhima Raj	Single bulb selection up to three generations followed by mass selection	Lawande et al. (2009, 2011b)
36	Bhima Shakti & Bhima Kiran	Mass selectionfor late kharif and rabi season with better storability & mass selection for rabi with good keeping quality	Lawande et al. (2010)
37	Bhima Shweta	Selection of elite lines from germplasm followed by random matting and mass selection for rabi season white onion	Mahajan et al. (2010)
38	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)
39	Bhima Safed	Selection of white segregating bulb from red onion variety Bhina Super and further mass selection for white populations for kharif kharif season	Mahajan et al. (2019)

selection, intra-varietal recurrent hybridization, backcross for transfer of desirable characters (Pike 1986; Ram 1998; Peter and Pradeepkumar 2008; Gupta & Singh 2017; Gupta et al. 2021).

Role of organizations in development and release of onion varieties and hybrids

There is great role of developed varieties, which are recommended for different climatic zones, which resulted in increase in production and productivity of onion in India. There is a need to popularize and multiply seeds of recommended varieties in large scale, which will result in increasing the farmers' income. It will also help to get more returns through export to the farmers. Varieties are notified by either the central varietal release committee (CVRC) or state varietal release committee (SVRC) for commercial utilization. Hence, these are extensively evaluated for their performance in multi-location trials conducted under the AICRP-VC or AINRPOG, which play a key role in testing, identification and release of new varieties. Varieties in onion were developed by different SAUs and ICAR institutes are tested under coordinated/ network project for release at national level for different agro-climatic conditions. Till now, about 70 onion varieties including two F_1 hybrids and six multiplier onion varieties have been developed and released from public sectors for different colours (Light red, dark red, white and yellow), types (Common, rose and multiplier type), locations (short and long day) and seasons (Kharif, late Kharif and Rabi) at state or national level. Out of which more than 33 onion varieties have been released through AICRP-VC/ AINRPOG including 10 onion varieties from ICAR-DOGR, Rajgurunagar.

Seasonal orientation of onion production

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, pests and poor storage of Kharif produce, farmers in Western Maharashtra are inclining towards late Kharif crop, commonly called as *Rangda* onion. Seedlings are transplanted in September-October and bulbs are ready for harvest in January-February. Low temperature during November-December favours bulb initiation and good development. Warm days during January-February facilitate maturity, as the day length available is again 11-11.5 hrs. The yields are high with good bulb size but percentage of bolting and twins is very high and therefore reduce marketable yield. Further, storability of bulbs is also low as compared to *rabi* produce. The varieties like Bhima Shakti and Bhima Shubra developed by ICAR-DOGR and Phule Samarth developed by MPKV, Rahuri are recommended for late *kharif* season. Still there is need to intensify research work in India for different location for late *kharif* season for early arrivals in market.

Productivity of *kharif* onion in Maharashtra, Karnataka, Tamil Nadu, Rajasthan and Madhya Pradesh needs to be ensured as per recommendations of ICAR-DOGR, Rajgurunagar. Selection of suitable varieties, planting on raised beds in broad bed furrows and drip irrigation with advance production technology fertigation technique, IPM and IDM ensure higher productivity in *kharif* onion. To ensure a steady supply of onion in the nation with control over price and better remuneration to farmers and to sustain export, there is need to ensure higher productivity during *rabi* by adopting recommended varieties of onion with good storage along with onion production.

Adaptation of onion production to climate change vagaries

Climate change due to global warming and pollution has become major concern to the crop scientists, and how to address this and prepare for is an important issue. Effect on total ecology and subsequently on certain important commodities is really not being studied. Hence, there is need to take up systematic studies. The 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. Sudden rise in temperature in *rabi* season during December-January result in poor bulb initiation and bulb development. Dry weather with high temperature favours incidence of thrips and mites. Very high temperatures in March-April-May lead to reducing keeping quality of onion bulbs. Work on development of photo and thermo insensitive varieties is undertaken at ICAR-Directorate of Onion and Garlic Research, Rajgurunagar to tackle the changing climatic situations. Some of the germplasm were found promising and can be grown in all the three seasons Kharif, late Kharif and Rabi and varieties being exploited for such situations. Varieties like Bhima Super, Bhima Red, Bhima Raj and Bhima Shweta gives photo- and thermos-neutral response have wider adaptability and can be cultivated in all the three seasons under short day plains as well as under long day hill conditions.

Onion seed requirement

Quality seed and planting material is very important. Requirement of onion seed is approximately 13000 tons every year. Each state should ensure area for seed production to fulfil the desired quantity of seed in their own state, or may contact other states in advance, so that sufficient quantity of bulb can be stored, considering the storage losses and planted for seed production. Surplus seed should be produced keeping in view, seed requirement in next year and stored in cold store with proper packing and appropriate seed moisture to fulfil the requirement of quality seed and to stabilize onion seed price and availability of quality produce for export.

Characteristics of an ideal bulb

Bulb should be attractive, uniform in size, shape, colour and time of maturity. It should consist flavour (pungency), high dry matter and long storage life. Additional desirable features are intact and attractive skin, thick leaf scales (rings), single centred bulb, thin neck and resistant to early bolting, diseases and pests. Each of these characteristics is genetically inherited but can be modified by environmental and cultural practices. Hence, there is need to develop varieties for different seasons, biotic and abiotic stress, processing, green foliage, export quality, mechanized farming for large as well as small farmers, better keeping quality, organic cultivation, set planting, face climate change, early maturity, tolerant to bolting and finaly according to consumers' demand of our country and export demand of different countries. Therefore, adoption and acclimatization of onion has undergone continuous selection by onion growers to suit as per climate and market demands. Local type cultivars like Nasik Red, Poona Red, Patna Red and Bellary Red are the result of selection by growers. As a result, a number of varieties of onion have been developed (Lawande 2003 & 2004, Lawande et al. 2011).

Germplasm resources in India: The onion germplasm is being maintained by the various public sector institutions in India like ICAR-Directorate of Onion and Garlic Research, Rajgurunagar, Pune; ICAR-National Bureau of Plant Genetic Resources (NBPGR), New Delhi; ICAR-Indian Institute of Horticultural Research, Bangalore; Mahatma Phule Krishi Vidyapeeth, Rahuri; National Horticultural Research and Development Foundation, Delhi; ICAR-Indian Agricultural Research Institute, New Delhi; Punjab Agricultural University, Ludhiana; Tamil Nadu Agricultural University, Coimbatore; ICAR-Central Institute of Temperate Horticulture, Srinagar; and ICAR-Vivekananda Parvatiya Krishi Anusandhan Shala, Almora.

Selection techniques/criteria in onion

1. Yield evaluation at uniform density.
2. Maturity- time of foliage collapse.
3. Bolting- good assessment by early sowing.
4. Quality assessment- Visual: Colour, Skin retention, Neck thickness, Shape and uniformity
5. Widely recognized phenotypic correlations between large size, softness, low pungency and poor storage ability should be taken into account.
6. Storage capacity– Dormancy is important because onions are normally stored for longer time. By storing bulbs in ambient conditions, marketability, losses due to rotting and sprouting can be recorded.
7. TSS– High TSS is important for dehydration industry producing onion chips and powder.
8. For export: Varieties are to be developed depending on the demand of different countries for shape, size, colour, pungency, TSS, etc.

Breeding methods in onion

The improvement of onion crop has not attracted much attention by the breeders in India. Perhaps, because of biennial habit of the crop requiring longer time for breeding and difficulties in attaining and maintaining genetic uniformity due to high degree of natural cross pollination and rapid inbreeding depression. Though, number of varieties have been developed in India, still there is enough scope to develop varieties with high total soluble solids suitable for dehydration, short day yellow varieties for export and varieties resistant to diseases and insect pests and suitability to different seasons. Baring few exceptions, the breeder stock of many varieties are not being maintained properly. Some of them never reached to farmers. However, few varieties always remained on the forefront. Despite release of high number of varieties, area under them is not more than 30 per cent. Remaining area is covered with the types maintained by the farmers themselves. Easier seed production for home requirement, at farmers' site is the main hurdle for spread of improved varieties. Non-availability of sufficient seed at reasonable price is the secondary one and finally, probably farmers have not overcome the presumption that all new varieties are *on par* with their material being maintained traditionally. All varieties developed so far and local types

maintained by farmers suffer from all disease and pest, high percentage of twins, bolters and multi-centered bulbs and minor variations in colour, shape and maturity (Mahajan & Lawande 2011). The improvement of onion crop has not received any attraction of the breeders in India. Perhaps, it is because of biennial habit of the crop requiring longer time for breeding and difficulties in attaining and maintaining genetic uniformity due to high nature cross pollination and rapid inbreeding depression. Besides, lack of facilities for storage of selected bulbs of breeding lines in controlled storage conditions is another factor for slow progress in onion breeding programme (Swarup 1991).

Introduction: Early Grano and Brown Spanish were introduced and acclimatized for growing in Indian conditions. Brown Spanish is a long day type variety grown on hills.

Population improvement (Mass selection): Being cross-pollinated crop, onion always provides a scope for using new population improvement methods, as natural variability is created constantly. Tremendous amount of variability is being utilised in onion using various breeding procedures. Different gene actions and gene combinations identified by genetic studies are being employed for generating new varieties and developing material for making 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. However, 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 (Mahajan and Lawande 2011).

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. A number of workers have reported both General Combining Ability (GCA) and Specific Combining Ability (SCA) estimates for various parental lines. There were highly significant GCA effects for both these characters and some evidences for relatively smaller significant SCA effects. 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 (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. The simplest one being mass selection, starting with a chosen parent population, the best approximately 1-5% 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 (Brewster and Robinowitch 1990). Further, Akgun (1970) developed three varieties with spherical bulbs, yellow skins and white flesh through mass selection in the variable population of Marmara and single plant selection in that of Thrace Yalova 1 with 15%, Yalova 3 with 10% and Yalova 12 with 16.5% of dry matter. Yalova 3 can be multiplied from seed, while the other two are propagated from sets and bulbs. Efimochkina (1970) improved Spasskii, an ancient Russian variety, for the commercial quality, yield, ability to mature, firmness and keeping quality practicing mass selection and intravarietal recurrent hybridisation. A genetical analysis of cross between a Japanese Autumn sown × European Spring sown onion was undertaken by DeSouza (1985) using sophisticated triple test cross design. Early growth, maturity, yield per unit area, bulb weight, size, shape and quality characters were examined and in all characters evidenced the significant additive genetic variance.

Arka Kalyan (Sel-14) was developed in 1987 (IIHR, Bangalore) through mass selection from IIHR 145 having globe shaped bulbs with medium large size, deep red coloured outer scales and fleshy succulent internal scales, average bulb weight of 130-180 g, pungent, TSS of 11-13%, moderately resistant to purple blotch caused by *Alternaria porii*, seed yield 8 q/ha, suitable for *Kharif* season, matures in 140 days, and yield is 47 t/ ha.

In Italy, Fantino and Schiavi (1987) intimated the use of mass and recurrent selection to develop the resistant

lines for *F. oxysporum* f. sp. *cepae* Snyd. et Hans., as it is main onion disease and causes serious damages both in the field and during the storage period. Cultivar "Dorata di Parma" was used for enhancing bulb traits and tolerance to *Fusarium* in 1975 using mass selection on naturally infected soil and three systems of recurrent selection (half-sib, S sub(1) and S sub(2)) on naturally infected soil and by means of artificial infection. The selected populations showed a percentage of rotten bulbs twice lower than that of the commercial populations of "Dorata di Parma", and similar to the medium tolerant hybrids Cosmic and CMW 745. Sudanese onion types and landraces have developed a high frequency of heterozygosity and heterogeneity and exhibit a wide genetic variability in many traits as they were being intercrossed with various introductions from Egypt, USA and West Africa, as well as between themselves. Hudeiba Research Station in northern Sudan, using the local germplasm, released three varieties for different purposes in 1987. Similarly, Nazareth Horticultural Research Station, Ethiopia developed commercially viable seed-grown varieties which were being used locally and exported using the Sudanese germplasm during 1970s and 1980s (Mohamedali, 1995).

Additive gene effects for dry matter content, bulb size and maturity and additive and non-additive gene effects for bulb yield and number of leaves per plant were found to play important role. In India efforts are being made to develop purple blotch resistant varieties, but so far no durable resistant variety is available. However, Selections 11–1–1 and IIHR-25 are reported to be resistant from IIHR, Bangalore and Punjab Red Round and Punjab Narroya (PBR-5) are reported from PAU and tolerant to purple blotch (Singh 1997). IPA-Empresa Pernambucana de Pesquisa Agropecuária, based at state of Pernambuco, Brazil released short-day yellow cultivars tolerant to *C. gloeosporioides* and *T. tabaci*, associated to good post-harvesting conservation, 'Composto IPA-6'. Again, 'Belem IPA-9' was released, having as main characteristics like good yield performance, adaptation throughout the year, and a remarkable tolerance to *C. gloeosporioides* (De Franca and Candeia 1997). Mani et al. (1999) used mass selection for exploiting general gene effect and additive × additive type of gene interaction in a cross combination 'In-13 × L-43'. Three cycles of mass selection of the F_2 of this combination led to the development of an improved high yielding onion strain 'VL 3'. This high yielding open pollinated variety, designated as 'VL Piaz 3' was identified by All India Vegetable Improvement workshop during 1990 for hills and plains of Uttar Pradesh.

La Consulta Experiment Station, Argentina released three cultivars namely Cobriza INTA, Navideña INTA, and Antártica INTA (Galmarini *et al*., 2001) aiming the goals of earliness and good storage quality in long-day cultivars, introduction of pink-root resistance and high dry matter into cultivars for the dehydration industry. Cobriza INTA was a selection from Valenciana type onions. The yield was similar to Valcatorce INTA; cultivar that covers most of the area in Argentina, but with greater bulb quality. Navideña INTA was selected from a Torrentina local population; and was an intermediate adapted cultivar with brown bulbs with three colored scales, and low pungency and Antártica INTA was a long day cultivar, obtained by selection from Valenciana type onions with white round bulbs, 14% soluble solids, and good keeping quality.

At Kheir-Abad Agricultural Research Center, Zanjan, Iran, mass selection method was used in order to congregate the desirable genes in local onion population of Gholy-Ghesseh in 1998-2002 (Javad et al. 2004). Initially single bulbs were selected based on bulb characters like (bulb weight, bulb diameter, bulb height, bulb neck, total biomass, bulb performance, and per cent of sprouting bulbs) number of flowering stems number of leaves, leaf weight, plant weight, dry matter, during storage period. But presence of significant negative genetic correlation between double bulbing and neck bulb- being important economic characters of onion- confirmed the idea that simultaneous mass selection of these two characters is not efficient in onion breeding. Tiemens-Hulscher et al. (2006) did experiment for searching the onion varieties which are better adapted to organic farming. Two organic onion farmers and one conventional onion breeder were asked to follow positive mass selection method in three segregating populations under organic conditions. Selection in the field for earliness and downy mildew and after storage characteristics was followed. Farmers and breeder also applied identical selection directions for bulb traits as a round shape, better hardness and skin firmness. Resultant bulbs were bigger than in the original population. Bakheet (2008) adopted two breeding methods, phenotypic recurrent mass selection and inbreeding followed by bulking for purifying the popular land variety "Abu Ferewa" selecting for high yield, high dry matter content in addition to uniformity of colour, shape and size and against doubling and premature bolting with good storability at ambient condition at Shambat Research Station, Khartoum North Sudan, during 2004/05 through 2006/07 seasons. Recurrent mass selection method was found to be more efficient by 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.

In UK, public sector work at National Vegetable Research Station (NVRS) has concentrated on the relative merits of population improvement in "Rijnshurger". In western Germany, improved varieties based on cv. "Zittauer Gelbe" have been bred. In Eastern Europe, all breeding research and production of improved varieties is conducted by the state. Many countries have developed successful locally adapted open pollinated varieties e.g. "Wolska" and "Rawska" (Polland) and "Vsetatska" (Czeckoslovakia). The Hungarian variety cv. "Makoi" has exceptionally high dry matter content. In New Zealand, mass selection by local growers led to the development of successful open pollinated variety "Pukekohe Longkeeper". It is expected that new open pollinated varieties will continue to be required in those countries where the grower is unable to pay for high cost of F_1 hybrid seeds (Brewster 2008).

Bhima Super was developed by rigorous mass selection for single centeredness up to 7 generations and able to achieve more than 95% single centred bulbs with uniform desirable shape of bulb in India for *kharif* season (Lawande et al. 2007). Bhima Red and Bhima Raj were developed by single bulb selection up to three generations from B-780 followed by mass selection (Lawande et al. 2007, 2009). Bhima Shakti (Red) and Bhima Kiran (Light red) were 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 was developed by selecting white onion elite lines from germplasm followed by random matting and further mass selection for three generations by 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)

Family selection: More sophisticated open pollination breeding schemes are based on family selection. Many of desirable agronomic characters are quantitative in nature and heritabilities are based on the individuals are low. In these circumstances, using family mean performance, rather than individual bulb as unit of selection can operate more efficient selection scheme. Commonly half-sib families or one and two generation selfed families are used. Number of families selected and number of cycles of selection is not necessarily fixed. New promising lines may be brought in the schemes at any stage of selection. The schemes operate at the alternate field evaluation of bulbs and controlled seeding of selection in consecutive seasons. Both, the intermediate "improved" population and final variety created by intercrossing of selected bulbs from selected families by mass pollination in isolation are useful. The final variety may be maintained by mass selection in subsequent generations. Continuously population improvement methods are being used for development of the cultivars for various purposes. Wall et al. (1996) used half-sib family analysis and selection response to estimate heritability of the pungency and single center in onion breeding populations.

Mutation breeding: The field of mutation breeding has greatly changed with an induction of artificial transmutation of gene by X-rays. Radiations and chemical mutagens are the potential mutagenic agents for induction of mutations. Advances in mutation research have provided an opportunity to induce and identify different types of mutants. A few of them have been used for commercial cultivation as new varieties; however, the majority of induced qualitative mutants are recessive and deleterious. In onion, chemical mutagens viz., ethyl-methane sulphonate, N-methyl-N-nitrosourea and ethyl-imine along with gamma rays have been used. However, till date significant improvement has not been achieved.

Recurrent selection: Population improvement methods were applied to the spring-sown bulb onion crop. Partially inbred populations were also developed from synthetic populations, by half-sib selection methods. Synthetic populations were developed by recurrent selection based on selection of inbred lines by their *per se* performance for improved yield, bulb quality and storage performance (Dowker et al. 1984). Further, Cramer (2001a, 2001b) and Wall and Corgan (2002) released two and one cultivar(s), respectively with different aims in different areas using recurrent selection method of population improvement. These are NuMex Arthur' Onion: low-pungency, high yielding, pink-root-resistant, intermediate-day, open-pollinated, yellow onion cultivar for spring seeding or transplanting in southern New Mexico. This cultivar was ideal for fresh market onion consumption. NuMex Chaco' Onion: single-centered, bolting-resistant, pink-root-resistant, early maturing, short-day, yellow onion cultivar for fall seeding in southern New Mexico. It was found that 'NuMex Chaco' produces a higher percentage of single-centered bulbs than any other fall-planted cultivar grown in southern New Mexico and is highly suited for onion ring processing and NuMex Snowball' Onion: late-maturing, pinkroot-resistant, round, hard, intermediate-

day, white-colored onion cultivar for spring seeding in southern New Mexico and similar environments.

Reciprocal recurrent selection breeding method was suggested by Evoor et al. (2007), to exploit all the gene actions simultaneously to develop a new resistant line/ variety, as it is the best method to improve trait of resistance to purple blotch disease. Genetic analysis in six generations (P1, P2, F1, F2, B1 and B2) of four onion crosses viz., PBR 138 x AN 187, PBR 139 × AN 184, PBR 139 × AP 195 and PBR 140 × AN 184 to study the inheritance of resistance to purple blotch disease both under natural epiphytotic condition and artificial inoculation method, revealed that both additive (*d* and *i*) and non-additive (*h*, *j* and *l*) gene action were significantly operative in all the crosses. However, the interaction dominance × dominance and dominance type of gene action was predominant. Duplicate type of epistasis was observed in all crosses.

Pedigree Selection: Zhaoshui (1995) conducted two cycles of maternal pedigree selection in male sterile-plants (MPSMS) and maternal pedigree selection in male fertile plants (MPSMF) in a local variety. Progressive regression and path coefficient with three replications was used for the screening and analysis of components of white shaft weight. The results showed the difference in components of white shaft weight in MPSMS and that of MPSMF. In green onion breeding for high weight of white shaft, increasing white shaft length was found to be the best selection criterion in MPSMS, whereas it was white shaft diameter in case of MPSMF. IIHR, Bangalore, developed Arka Pitambar through pedigree selection from the cross U.D. 102 × IIHR-396, with Medium size (5.2-6.0 cm) bulbs having globe shape and thin neck. Mild pungency with TSS 11% and total sugar 9.81%. It was also tolerant to purple blotch, basal rot diseases and thrips.

Hetereosis breeding: Male-sterile line is crossed with a pollen donor to produce F_1 hybrid with desirable traits. Jones and Clarke (1943) maintained their male sterile lines vegetatively using the bulbils produced in the flower head. However, bulbils are difficult to store and viruses tend to accumulate in the plants. Male sterile lines are maintained by male-fertile 'maintainer lines' with the genetic constitution *Nmsms*. Such a line will produce pollen which can fertilize the male-sterile line, but its offspring has the constitution *Smsms*, and is therefore male sterile. Using these two lines it is possible to propagate the male-sterile line from seed. Once a maintainer line has been identified in a locally adapted inbred population, the male-sterile line must be developed so that it is near-identical genetically to it, apart from the presence of the *S* cytoplasmic factor. This is done by repeatedly back crossing the male-sterile offspring with the original *Nmsms* adapted maintainer line. With each generation of such a cross, the genetic contribution from the original sterile *Smsms* parent is diluted by a factor of two, so that after four generations of this 'backcrossing' 96.87% of the genes in the resultant *Smsms* line derive from the original *Nmsms* line, and it is isogenic similar to use as a male-sterile line in test crosses to identify vigorous hybrids (Gupta and Singh 2017). When large numbers of test crosses are made, only certain crosses result in desirable F_1s. Therefore, a number of adapted male-sterile and maintainer lines needs to be used in development of F_1 hybrid. The breeder must make many crosses on to his male-sterile lines and grow and evaluate the progeny to identify which give desirable hybrids. By accumulating data from such test crosses he can build up information which help to predict which crosses will produce good hybrids.

In USA and Japan, F_1 hybrids occupy large growing areas, while in European countries like Netherlands, UK and many others, the open pollinated varieties are more commonly grown than F_1 hybrids. Heterosis for yield, earliness, uniformity, storage quality and dry matter content has been reported by many workers. In 1959 onion hybrids in New York surpassed open pollinated varieties by 30% in yield and increase in storage life up to 40%, which stimulated the growing of F_1 onion hybrids in the northern United States and Canada. Variety protection was a second strong stimulus for popularity of F_1 hybrids in onion.

Commercially available F_1 hybrids suitable for tropical regions are mainly of the yellow skin type, and these have generally poor storage life. In USA almost 100% area in onion is under hybrid. Some of the male sterile lines have been developed in India but in most of the cases the sterility is not stable and secondly the inbred lines developed are not pure, particularly in onion due to inbreeding depression, long breeding cycle, less storage life of seed and difficult seed production process of the inbreds and male sterile lines. Very few seeds are obtained in manual crossing which is commercially not possible. First attempt for the development of hybrid in India in onion was made as early asin 1948 using exotic male sterile lines. But these exotic male sterile lines were found unsuitable in the short day conditions of our country. Despite reports on high percentage of heterosis, the hybrids in onion have not made headway in India due to non-availability of stable male sterile lines along with maintainers in short day onion. The work got momentum in eighties at IIHR (Bangalore), IARI (New Delhi) and MPKV (Rahuri). At IARI, the male sterility

was isolated in a commercial variety 'Pusa Red'. Only two onion hybrids 'Arka Kirthiman' and 'Arka Lalima' have been released from IIHR. Some new hybrids have been developed in India which is under various stages of evaluation. Some of the exotic hybrids are performing well during late *kharif* in Indian conditions and yield are almost double than the Indian varieties at DOGR, but they have very less TSS, less storage life and are of yellow colour which has no consumer preference in India. It can be exploited to trap the European and Japanese market where there is great demand, but it can be possible only through cool chain export. Consumers' preference towards adaptation of these high yielding hybrids can be developed in our country.

Unfortunately, absence of male sterile lines along with maintainer in short day onion in India always remained a bottleneck in heterosis breeding programme. Private seed companies recently started selling F_1 hybrids. However, rigorous testing is required in different agro-climatic zones for different purposes. Knowing the importance of F_1 hybrids, DOGR has started research on F_1 hybrids in onion. Trails conducted at DOGR on exotic F_1 hybrids in yellow type exhibited very good performance in late *kharif* and *rabi* seasons. Out of 90 exotic onions tested during 2000 to 2008, more than 20% higher yield was recorded in 10 exotic onions during late *kharif* over 'Bhima Super' and 16 exotic during rabi season over 'N-2-4-1' in Maharashtra conditions. Yield increase was recorded up to 37.84% in late *kharif* and 57.41%in *rabi* over respective checks of best open pollinated varieties. Further, F_1 hybrids developed at ICAR-DOGR by using four CMS lines is under evaluation in hybrid trials of AINRP Onion and Garlic programme.

Breeding for seasonal adaptability

Commercial onion in India is grown in the regions between 12 to 25^0 N latitude (Mahajan and Lawande 2008). Kharif crop is grown during hot and humid months and ready for harvest when temperatures are low. The bulbs do not become 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 value of day length available is around 11-11.5 hrs due to cloudy weather. Through centuries of selection the types, which can respond to warm and humid days with 11-11.5 hrs, have been identified and maintained by 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. N-53 is now out dated variety.

In case of winter (*rabi*) crop seedlings are transplanted in November-December, low temperatures (20-25^0 C) during December-January favour bulb initiation under again short day conditions i.e. 11-11.5 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 is better curing of neck and such bulbs store well up to 5-6 months. Bulb quality is good. 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 is among these recently recommended having dark red bulbs with good keeping quality during *rabi* season.

In hills of Uttar Pradesh, Himachal Pradesh, winter 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 (high TSS) 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 tonnes/ha against 30 tonnes in countries located between 25-30 ^{0}N latitude (Sheshadri and Chaterjee 1996).

Staggered planting in different seasons warrantee 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 is 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. Late Kharif season is becoming more popular in Maharashtra due to high yield and less hazards of diseases and pests. High percentages 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

Dehydrated products such as flakes, rings, granules, powder etc and processed onion as onion in vinegar and brine are the important byproducts being prepared and marketed world wide. Processing industries in any commodity play an important role in stabilizing prices in domestic markets. Dehydration industries demand for white onion varieties with globose shape of bulb and high TSS (>18%), but most of the Indian white onion genotypes are having TSS range between 11-13% (Table 2). Model variety for dehydration should be pure white, with globose shape, thin neck, free from greening and moulds, high pungency and high TSS. The variety should be high yielding with field tolerance/resistance to diseases and pests. Wider seasonal adaptability is also an important character from continuous supply point of view. TSS and pungency is a function of genotype, cultural practices and environment. Indian varieties are short day type mature within 90-120 days. They are basically low TSS varieties. The TSS varies from 10-14% in Indian material. Some of the long day varieties which mature within 150-180 days offer high TSS range from 15-24%. But long day varieties do-not produce bulbs under Indian short day conditions. However, intermediate short day varieties produce good bulbs but seed production is not possible under plains.

Table 2: Performance of white onion varieties developed in India

Sl. No.	Name of Variety	Source	T.S.S. %	Average yield (q/ha)
1.	Pusa White Round	IARI, New Delhi	11.13	300 – 325
2.	Pusa White Flat	IARI, New Delhi	10.00	325 – 350
3.	Udaipur 102	RAU, Udaipur	10.06	300 – 350
4.	Agrifound White	NHRDF, Nashik	10.76	200 – 250
5.	Phule Safed	MPKV, Rahuri	10.13	250 – 300
6.	PKV White	PDKV, Akola	09.55	250 – 300
7.	Gujarat White	JAU, Junagadh	-	300 – 325
8.	N-257-9-1	Agril. Deptt., M.S.	10.00	250 – 300
9.	Punjab-48	PAU, Ludhiana	11.00	300 – 325
10.	V-12	Jain Food Park	15.00	350 – 400
11.	Nimar Local	Land Race, M.P.	12.50	250 – 300
12.	Talaja Local	Land Race, Bhavnagar	12.00	250 - 300
13.	Bhima Shubra	DOGR, Rajgurunagar	11.00	180 – 200 in kharif & 350 – 400 in late kharif
14.	Bhima Shweta	DOGR, Rajgurunagar	11.50	180 – 200 in kharif & 260 – 300 in rabi

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 (Mahajan and Lawande 2011). After assessing Indian varieties and land races which donot offer TSS range more than 12 per cent. Jain Food Park Industries, Jalgaon introduced White Creole, which further subjected to selection pressure, for high TSS character and developed V-12 variety with TSS range from 15-18%. This variety is under contract production for processing but seed production is not possible under Indian plains.

Since establishment of NRC for Onion and Garlic in 1998 at Rajgurunagar (now ICAR-DOGR), a special programme for development of high TSS white onion variety was launched through selfing and massing from available germplasm. In the year 2000, about 7199 bulbs were examined for TSS range. Only 2.72% bulbs recorded TSS more than 14 per cent. 109 bulbs offering TSS range from 15 to 23% were selfed and populations were developed. After rejecting poor performing populations, 30 populations having 16 to 19% TSS are advanced. In 6th generation of selection cycle we are able to achieve more than 85% bulbs having average TSS about 18% or even more in about 15 populations in short day onion. It would be possible to develop high TSS open pollinated varieties within 2-3 years time suitable for *rabi* and late *kharif* seasons (Mahajan and Lawande, 2011). Other options of mutation breeding are also being tried. Kataria (1990) reported three white mutants developed through chemical and physical mutagens viz., 22-5-1-1, 22-9-2-2 and 106-13-1-1 having TSS range from 25-30 per cent. This excellent material never reflected further in the form of either commercial variety or breeding material for varietal improvement.

Breeding for export

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 is shape size and colour is seldom attained, as there 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. ICAR-DOGR 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 for development of varieties in dark red and light red colour 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 this Directorate in collaboration with CITH Srinagar. Crosses were made and further selections for desirable characters were done which is further followed by mass selection (Mahajan and Lawande 2011) and are in 6th generation of selection.

Indians do not prefer yellow onion but these find international market in European. Minimum requirements for export are: bigger sized (>60 mm diameter), less pungent and single-centered types. As is evident, most work has been done in European countries and USA whereas, in India, research on onion has not been of any great significance. "NuMex Starlite", a new yellow-onion variety developed by Corgan and Holland (1993), was resistant to bolting, *Pyrenochaeta terrestris* and the short-day type was obtained by 5 recurrent selections from Texas Grano 502 PRR. Among the 12 short-day onion cultivars assessed at Hermosillo, Mexico (Warid and Loaiza 1996), all the yellow cultivars had high yields. Seville, 9003C, Bravo, Quest and Sweet Perfection gave [and were graded Jumbo (3-4 inches in diameter)] highest marketable yields of the 30 yellow cultivars tested over 2 years (Shock et al. 2000) and had the most numerous bulbs. Texas 'Grano 1015 Y', a mildly pungent, sweet, short-day yellow onion variety, was developed by Pike *et al.* (1988a) through original, single-bulb selection from Texas Early Grano 951 through 5 generations of selections. Similarly, "Texas Grano 1030 Y" was developed from F2 selections of Texas Early Grano 502 × Ben Shemen by Pike et al. (1988b), which is a late maturing mildly pungent short-day onion variety. Very little work has been done in India for development of yellow onion varieties, particularly for export. Only two varieties were developed, viz. Phule Swarna from MPKV, Rahuri and Arka Pitambar from IIHR, Bangalore and were released at the state / institute level. Yield of these varieties was comparatively less than in commercial red onion varieties. Mohanty et al. (2000) assessed 12 varieties of onion during *kharif* season and found lowest bulb diameter of 4.2 cm in Arka Pitambar, along with low yields.

Varietal development with special reference to climate change

Climate change due to global warming and pollution has become major concern to the crop scientists and how to address this and prepare for is an important issue. Effect on total ecology and subsequently on certain important commodities is really not being studied. Onion and garlic is no bar to this shortcoming. No systematic studies are done in this regard. 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. Sudden rise in temperature in *rabi* season during December-January result in poor bulb initiation and bulb development of *rabi* onion and garlic. Dry weather with high temperature favours incidence of thrips and mites on these crop. Very high temperatures in March-April-May lead to reducing keeping quality of onion and garlic bulbs. Detailed studies under simulated conditions of weather parameters need to be initiated for understanding critical impact of climate change on different crops. Work on development of photo and thermo insensitive varieties is undertaken at Directorate of Onion and Garlic Research, Rajgurunagar to tackle the changing climatic situations. Some of the germplasm were found promising and can be grown in all the three seasons *viz*., Kharif, late Kharif and Rabi seasons is being exploited for such situations (Mahajan et al. 2005, 2011).

Though onion is biannual in nature, extremely cross-pollinated crop, shows inbreeding depression, have less storage life of seed etc. But looking to the methods exploited in onion improvement in the world, there is lot of scope for population improvement in India also in following areas but one has to work with patience. There is need for identification of areas where off season seed can be produced or to standardize techniques of seed production during *kharif* season to reduce the time of breeding from biannual to annual particularly for late *kharif* and *rabi* season varieties. Some of the reports are available where efforts were made to produce seed during *kharif* season which was successful (Mahajan et al. 2002) and can be exploited for population improvement for *rabi* and late *kharif* onion varieties.

सारांश

एलियम समूह की सब्जियों में प्याज व लहसुन को बड़े पैमाने पर खाया जाता है और कच्चे एवं प्रसंस्कृति उत्पाद के रूप में भी उपयोग किया जाता है। भारतवर्ष के प्रत्येक घरों बनने वाले प्रतिदिन के भोजन में प्याज व लहसुन एक प्रमुख अवयव है जिसकी खेती खरीफ, पिछेती खरीफ तथा रबी के मौसम में की जाती है। रबी की फसल से 50 प्रतिशत से ज्यादा उत्पादन प्राप्त होता है। चीन के बाद भारतवर्ष प्याज व लहसुन के उत्पादन में दूसरे स्थान पर हैं। ऐसी किस्मों का विकास आवश्यक है जिसके कंद आकर्षक, समान आकार–प्रकार, रंग व एकसार पकाव, उच्च शुष्क पदार्थ एवं

भण्डारण क्षमता ज्यादा हो। साथ ही साथ अतिरिक्त वांछित गुणों जैसे–कंद के साथ लगा छिलका व आकर्षक छिलका, मोटी पत्ती छिलका जैसे– एक समान वलय, एकल केन्द्रियत कंद, पतली ग्रीबा व पूर्व पकाव पुष्पदंड विकास, रोग तथा कीट प्रतिरोधी होना चाहिए। इनमें अनुवांशिक रूप से वंशागतित्व लेकिन वातावरणीय तथा कृषि पद्धति परिवर्तन सम्भव हो, को स्थान देना चाहिए। अनेकों संस्थानों के शोध परिणामों द्वारा किस्मों व संकरों का विकास किया गया है। साथ ही साथ प्याज में उत्पादन तकनीकों से क्षेत्रफल, उत्पादन, उत्पादकता एवं निर्यात में वृद्धि हुई है।

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