CHAPTER 1

ONION RESEARCH AND TECHNOLOGY DEVELOPMENT: AN INDIAN PERSPECTIVE

J. Gopal

Director, Directorate of Onion and Garlic Research, Rajgurunagar, Pune - 410 505 (MS), India
director@dogr.res.in; jai_gopal@rediffmail.com

Introduction

Onion (*Allium cepa* L.) is one of the oldest cultivated species in use for more than 5,000 years as an integral component of various culinary preparations (Jones, 1983). Historical and cultural significance of onion in India has been well documented in Garuda Purana (Shastri, 1995) where it is regarded as *Rajasic* (having aphrodisiac quality). Being rich in thiosulfinates, thiosulfonates, allicin, aliin, ajoene and many other biochemical components, onion has medicinal value too. Charak in Charak Samhita (300 B.C.) described onion for diuretic, digestion, heart, eyes and joints problems. The modern medical science also recognized importance of onion in treating diversified ailments, *viz.* lowering blood sugar, cardiovascular problems, improving gastrointestinal health, fighting cholera, preventing hair loss, improving bone health, tooth disorders, urinary disorders, prevention of blood clot etc. (Corzo-Martinez *et al.*, 2007). The pesticidal and fungicidal properties of onion are well studied and widely accepted (Block, 2010; Begum *et al.*, 2013).

Onion Cultivation in India

The cultivation of onion in India occurred from very early times before the Christian era. Originally though native of temperate region of central Asia with perennial/biennial habit and long day character, it has established well in India under tropical and short day (11-11.5 hours) photoperiodic conditions (Seshadri and Chatterjee, 1996). During its acclimatization, farmers applied selection pressure involuntarily to meet the market preferences. Ability of onion to produce seeds indigenously has played an important role in adaptation. Out breeding mechanism present in onion has promoted selection suited to diverse environments during the process of adaptation and diversification. The adaptation to hardy conditions of high rainfall, high temperature and short photoperiod typical of rainy season crop of western India has been chronologically documented (Seshadri and Chatterjee, 1996). The tropicalization progressed further southwards towards Bellary region of North Karnataka and finally onion got established in Tamil Nadu (6 to 8^0 N latitude).

Two types of onion are commercially grown in India *viz.*, common onion and multiplier onion. Common onion (*A. cepa* var. *cepa)*, is the most important in commercial trade. Its bulbs are large, normally single and plants are propagated through seeds. The other group i.e. multiplier onion or shallot type onion (*A. cepa* var. *aggregatum* Don.) is vegetatively propagated and produce bulbs of small size and form an aggregated cluster. Multiplier onion is also known as country onion or potato onion or Egyptian ground onion. This is grown from ancient times in India. It has got a Sanskrit equivalent 'Palandu', mentioned in *Apastamba Dharma Sutra-I* (dated 800 B.C. to 300 B.C.), which confirms its early introduction in India.

In India, common onion is grown in three crop seasons i.e. *kharif*, late *kharif* and *rabi*. Main crop in *rabi* (50-60%) and 20-25% each in *kharif* and late *kharif*. *Kharif* crop is grown during hot and humid months and is ready for harvest when temperatures are low. The bulbs do not mature as growth continues due to cooler temperature and hence have poor storability. Although, the day length during this period is slightly longer than *rabi*, the critical period available is around 11-11.5 hours due to cloudy weather. Of late, due to delayed monsoon 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 forced farmers in Western Maharashtra to incline towards late *kharif* crop commonly called '*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 bulb development. Warm days during January-February facilitate maturity, as the day length available is again 11-11.5

hours. The yields are high with good bulb size but percentage of bolting and twins is very high resulting in reduced marketable yield. Further, storability of bulbs is also low as compared to *rabi* produce. In case of *rabi* crop, seedlings are transplanted in November-December. Low temperatures (20-25 ^{0}C) during December-January favour bulb initiation under short day conditions. Bulb growth and maturity occurs in February-March, when nights are cool and days are warm. High temperatures during April-May (35-40 ^{0}C) hasten maturity. There is better curing of neck and such bulbs store well up to 5-6 months. In hills of Uttar Pradesh and 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 hours) and temperatures are cool. Crop duration is long (>7 months). Due to congenial climate, growth and development is very good, bulb size is big resulting in higher yields.

Status of Research and Development on Onion in India

Systematic research and development (R&D) programs in onion were started in 1960 at Pimpalgaon, Baswant, Nashik and later on at Indian Agricultural Research Institute (IARI), New Delhi and Indian Institute of Horticultural Research (IIHR), Bengaluru. National Horticultural Research and Development Foundation (NHRDF), at Nashik established by National Agricultural Co-operative Marketing Federation of India Ltd. (NAFED) is carrying out research and development activities on export oriented crops, especially onion and garlic. Development of multiplier onion varieties was done by Tamil Nadu Agricultural University (TNAU), Coimbatore. Prior to this, research on collection and maintenance of landraces and standardization of agro-techniques was attempted by State Agricultural Departments. With the concept of coordinated projects and Agricultural Universities, the work on onion research was strengthened, in terms of varietal development for different seasons and standardization of production techniques in early nineties. The R&D in onion got impetus with the establishment of National Research Centre on Onion and Garlic at Nashik in 1994. This centre was shifted to present location at Rajgurunagar in 1998 and upgraded to Directorate with the addition of All India Network Research Project on Onion and Garlic in 2008. Besides concentrating on genetic improvement and biotechnology of onion, Directorate of Onion and Garlic Research (DOGR) is also working on development of agro-technologies including post-harvest management practices. This work is also being supplemented by NHRDF and some universities. At present different state agricultural universities, ICAR institutes across the country and private companies are working on different R&D aspects to improve and sustain production and productivity of onion. The status of work conducted in India in areas of onion improvement, production, protection and post-harvest management is presented below.

Crop Improvement

Genetic resources: A large numbers of landraces including some wild species are available in India particularly in the North-eastern states. As per reports from Singh and Rana (1994), National Bureau of Plant Genetic Resources (NBPGR) has conducted extensive plant exploration in different allium-growing states/regions in India. Kale *et al.* (1994) undertook a detailed survey of traditional and non-traditional onion-growing areas of the state of Maharashtra, and India in general, and collected 148 red-skin and 33 white-skin types of onion, evaluated and identified some lines on the basis of maximum average bulb weight, high TSS and centerness. According to Singh and Rana (1994), some of the cultivated Indian accessions have been identified to be resistant/tolerant to purple blotch (*Alternaria* species), *Stemphylium* blight and garlic mosaic virus. However, sources of resistance to many diseases and pests such as neckrot (*Botrytis allii* Munn.), basal rot (*Fusarium* species), black mould (*Aspergillus niger* Tieghem) are yet to be identified.

Many farmers in various parts of the country are growing old landraces of onion. For example, Pune Fursungi, a red coloured landrace is being cultivated in Nashik and Pune areas of Maharashtra in late *kharif* and *rabi* seasons. The Junagarh, Saurashtra and Mehsana areas of Gujarat are dominated by Pili Patti, which is commonly grown in *rabi* season. Bellary Red, another red onion landrace is prevalent in Karnataka and landrace Sukhsagar is being cultivated in West Bengal. K.P. onion dominates in Andhra Pradesh, whereas Nirmal Local occupies large area in Madhya Pradesh. Further, the multiplier type of onion has been a unique feature in Tamil Nadu. This variability is being maintained in national germplasm collection of onion at DOGR, which is the National Active Germplasm site for onion. The present status of collection of germplasm at DOGR is given in Table 1.

Table 1: Status of onion germplasm collection at Directorate of Onion and Garlic Rresearch.

Sr. No	Category	No. of accessions
1	Dark Red	274
2	Light Red	429
3	White	450
4	Yellow	50
5	Exotic onion	237
6	Wild species	12 (i) *Allium altaicum*, (ii) *A. ampeloprasum*, (iii) *A. cepa* x *A. cornutum* (PRAN), (iv) *A. cepa* x *A. fistulosum*,(v) *A. chinense*, (vi) *A. fistulosum*, (vii) *A. flavum*, (viii) *A. galanthum*, (ix) *A. guttatum*, (x) *A. hookeri*, *A. schoenoprasum* var. *schoenoprasum*, (xi) *A. tuberosum*

Genetic studies: Despite the global culinary and economic significance, genetic research in onion has greatly lagged than in other major vegetable crops. Actually, genetic analysis of onions is time consuming because of biennial nature and severe inbreeding depression. This makes it difficult to produce and maintain a large near homozygous inbred populations for genetic linkage analysis. Therefore, only a few qualitative genes with easily visible effects have been described in onion including colour of bulb, foliage, anthers and seed coats, male sterility, restoration in CMS, pink root resistance, ozone damage resistance, dwarf seed stalk and chlorophyll deficient mutants. However, a number of studies have reported inheritance of yield and quality traits, many of which were concerned with the estimation of combining ability in various populations. 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 (Joshi and Tandon, 1976; Pathak *et al.*, 1987).

Breeding: The commonly practiced breeding methods followed in onion are mass selection, recurrent selection, selfing and massing, hybridization followed by different population improvement schemes and heterosis breeding. The varietal improvement programme in India has originated from improvement of the local varieties. As a result more than 50 varieties of onion including 2 F_1 hybrids and 6 varieties of multiplier onion have been developed and released (Table 2). Most of these varieties are mainly for ***rabi*** season. Development of some *kharif* growing varieties was earlier done by Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, NHRDF, Nashik and IIHR, Bengaluru and later by DOGR, Rajgurunagar.

Despite reports of high heterosis (Joshi and Tandon, 1976; Aghora, 1985; Veere Gowda, 1988; Netrapal and Singh, 1999; Shashikanth *et al.*, 2007; Abubakar and Adu, 2008), 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. In India, progress in the development of suitable male sterile and fertile inbred lines has remained very slow. Sen and Srivastava (1957) attempted to develop F_1 hybrids in onion as early as in 1948 using exotic male sterile lines and Indian local male stocks. The exotic male sterile lines were found unsuitable in the photo periodically different environment in India. Later, very few workers attempted to test different hybrid combinations for heterosis and combining ability using male sterile lines (Pathak *et al.*, 1987). Male sterility has been isolated from indigenous germplasm by several workers in India; Patil *et al.* (1973) in *cv.* 'Niphad 2-4-1' and Pathak *et al.* (1980) in *cv.* 'Nasik White Globe'. Further studies indicated strong cytoplasmic factor responsible for male sterility in *cv.* 'Bombay White Globe' (Pathak *et al.*, 1986). At IARI, the male sterility was isolated in a commercial variety 'Pusa Red'. This male sterility has been transferred to several breeding lines by backcross breeding method. In a review on use of molecular markers in the improvement of allium crops, Reddy *et al.* (2013) detailed the information on male sterility system and their utilization in F_1 hybrids production. Only two onion hybrids 'Arka Kirthiman' and 'Arka Lalima' have been released from IIHR. Some new hybrids are being developed in the country. Gupta *et al.* (2011) reported that six F_1 hybrids *viz.* DOGR Hy-1, DOGR Hy-7, DOGR Hy-17, DOGR Hy-27, DOGR Hy-29 and DOGR Hy-41 were superior over standard check.

Table 2: Onion varieties developed by different organizations in India.

Sr. No.	Organization	Variety	Bulb color	Planting season	Year of release
1	Agril. Dept., M.S.	N-53	Red	*Kharif*	1975
2		*N-2-4-1	Red	*Rabi* and late*Kharif*	1985
3		*N-257-9-1	White	*Rabi*	1985
4	MPKV, Rahuri	Baswant -780	Red	*Kharif*	1989
5		Phule Safed	White	Late *Kharif* and *Rabi*	1994
6		Phule Suvarna	Yellow	*Rabi* and late *Kharif*	2001
7		*Phule Samarth (S-1)	Red	Late *Kharif*	2006
8	IARI, N. Delhi	Pusa White Flat	White	*Rabi*	1975
9		Pusa White Round	White	*Rabi*	1975
10		Early Grano (Long Day type)	Yellow	Late *Kharif* and *Rabi*	1975
11		Brown Spanish (Long Day)	Brown	Hills	1975
12		*Pusa Red	Red	Late *Kharif* and *Rabi*	1975
13		*Pusa Ratnar	Red	*Rabi*	1975
14		*Pusa Madhavi (Line-120)	Red	*Rabi*	1987
15		*Selection 126	Brown	*Rabi*	2012
16	IIHR, Bangalore	Arka Pragati	Red	*Kharif* and *Rabi*	1984
17		*Arka Niketan	Red	*Rabi* and late *Kharif*	1987
18		*Arka Kalyan	Red	*Kharif*	1987

Sr. No.	Organization	Variety	Bulb color	Planting season	Year of release
19		Arka Lalima (F1 hybrid)	Red	*Rabi*	1993
20		Arka Kirtiman (F1 hybrid)	Red	*Rabi*	1993
21		Arka Pitamber	Yellow	*Rabi*	2006
22		Arka Bindu	Red	*Kharif*, late *Kharif* and *Rabi*	2006
23		Arka Ujjwal (multiplier onion)	Red	*Rabi*	2010
24		Arka Swadista	White	*Rabi*	2010
25		Arka Vishwas	Dark red	*Kharif* and *Rabi*	2011
26		Arka Sona	Yellow	*Rabi*	2011
27		Arka Bhim (tri-parental synthetic)	Red	*Rabi*	2011
28		Arka Akshay (tri-parental synthetic)	Dark Red	*Rabi*	2011
29	HAU, Hissar	Hissar- 2	Red	*Rabi*	1976
30		*HOS-1	Red	*Rabi*	2006
31	NHRDF, Nashik	Agrifound Rose	Red	*Rabi*	1987
32		Agrifound Red (Multiplier)	Red	*Kharif* and *Rabi*	1987
33		*Agrifound Light Red	Red	*Rabi* and late *Kharif*	1988
34		Agrifound White	White	*Rabi*	1994
35		*Agrifound Dark Red	Red	*Kharif*	1996
36		*NHRDF Red (L-28)	Red	*Rabi*	2006

Sr. No.	Organization	Variety	Bulb color	Planting season	Year of release
37		* NHRDF Red (L-355)	Red	*Rabi*	2012
38	VPKAS, Almora	VL-67 (Long Day)	Red	Hills	1973
39		*VL-3 (Long Day)	Red	Hills	1990
40	RAU, Rajasthan	Udaipur 101	Red	*Rabi*	
41		Udaipur 102	White	*Rabi*	
42		Udaipur 103	Red	*Rabi*	
43	PDKV, Akola	*PKV White	White	*Rabi*	2009
44	GAU, Junagarh	Gujarat White Onion (GWO) - 1	White	*Rabi*	2000
45	CSAUAT, Kanpur	Kalyanpur Red Round	Red	*Rabi*	1983
46	PAU, Ludhiana	Punjab Selection	Red	*Rabi*	1973
47		*Punjab Red Round	Red	*Rabi*	1993
48		Punjab-48 (S-48)	White	*Rabi*	1978
49		Punjab White	White	*Rabi*	1998
50		*Punjab Naroya (PBR-5)	Red	*Rabi*	1997
51	TNAU, Coimbatore	Co-1 (Multiplier)	Red	*Kharif* and *Rabi*	
52		Co – 2	Red	*Kharif* and *Rabi*	1978
53		Co – 3	Red	*Kharif* and *Rabi*	1982
54		Co – 4	Red	*Kharif* and *Rabi*	1984
55		Co - 5		*Kharif* and *Rabi*	
56		MDU-1	Red	*Rabi*	1982

Sr. No.	Organization	Variety	Bulb color	Planting season	Year of release
57	RARS, Durgapura	Rajasthan Onion-1 (RO-1)	Red	*Rabi*	2004
58		Arpita (RO-59)	Red	*Rabi*	2005
59		RO 252	Red	*Rabi*	2010
60	DOGR, Rajgurunagar	*Bhima Super	Red	*Kharif*, late *Kharif* and *Rabi*	2006
61		*Bhima Raj	Red	*Kharif* and *Rabi*	2007
62		*Bhima Red	Red	*Kharif* and late *Kharif*	2009
63		*Bhima Shakti	Red	Late *Kharif* and *Rabi*	2010
64		*Bhima Kiran	Red	*Rabi*	2010
65		*Bhima Shweta	White	*Kharif* and *Rabi*	2010
66		*Bhima Shubhra	White	*Kharif* and late *Kharif*	2010
67		*Bhima Dark Red	Red	*Kharif*	2012

* Released through all India Coordinated Research Project on Vegetables or all India Network Research Project on Onion and Garlic.

Some of the exotic hybrids are performing well during late *kharif* under Indian conditions and yields 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 markets where there is great demand, but it can be possible only through cool chain export. However, the adaptation of the hybrids by farmers has been slow due to inherent problems associated with traditional onion production system in the country (Veere Gowda *et al.*, 2002).

Processed products of onion are in demand in many countries. Dehydration industries demand white onion varieties with globe shaped bulb and high TSS (>18%). Some of the varieties identified as suitable for dehydrated products were Punjab-48 (Bajaj *et al.*, 1979; Verma *et al.*, 1999), Roopali (Maini *et al.*, 1984), S-74 (Kalra *et al*,. 1986), Texas Yellow (Raina *et al.*, 1988) and PWO-1 (Saimbhi and Bal, 1996). After assessing Indian varieties and landraces which do not offer TSS range more than 12%, Jain Food Park Industries, Jalgaon introduced White Creole, which was further subjected to selection for high TSS and developed V-12 with TSS range of 15-18% (Mahajan *et al.*, 2011).

Biotechnology: Biotechnological approaches for crop improvement in onion are still in its nascent stage in India. DOGR has taken lead and has been successful in standardization of protocols for direct and indirect *in vitro* regeneration in onion. A preliminary insight into onion haploid development through *in vitro* gynogenesis has been achieved (DOGR, 2012). Somatic embryogenesis through direct regeneration and callusing has been achieved (Aswath *et al.*, 2006). Molecular markers (RAPD, ISSR and SSR) have been identified for estimating genetic diversity in onion, and related wild alliums. Development of core collection, conserving allium biodiversity and development of linkage maps in onion are being targeted. Sangeeta *et al.* (2006) used 90 RAPD primers and grouped the 24 onion cultivars into northern and southern region of India. Ten varieties of onion were analysed by Maniruzzaman *et al.* (2010) and found that Bermis and India-2 were most dissimilar while Faridpuri and Bhati were the most similar genetically.

Mitochondrial genome diversity has been evaluated by employing RAPD, SSR and RFLP markers (Chaurasia *et al.*, 2010). Dhanya *et al.* (2012) used RAPD markers analysis to investigate genetic relatedness among nine sterile (A), maintainer lines (B), and male parents (C) of onion. Radhika *et al.* (2013) used a computational approach for mining SSRs from ESTs in *A. cepa* and developed a database to store the unigenes, primer pairs, putative annotations and BLAST results, which can be used in studies related to marker assisted selection, detection of polymorphism, DNA fingerprinting and diversity analysis in onion.

Crop Production

In general, onion crop can be grown in the field by transplanting, direct seeding and sets method (Dhesi *et al.*, 1965; Yawalker, 1969). Technologies and practices have been developed for various stages of onion crop from sowing to harvesting.

Transplanting

Seed rate and seedlings: Studies on seed rate showed that depending on the variety, about 6-8 kg seeds would be sufficient for 1 ha by traditional transplanting method. About 0.05 ha area is required to raise the nursery for 1 ha area to be sown by transplanting. Seedlings should be grown on raised bed of 10-15 cm height with 1 m width and length as per convenience. The distance between two beds is kept 30 cm for easy intercultural operations. Seeds are manually sown in rows at 10-15 cm distance and irrigated preferably by drip or sprinklers. Seed treatment with *Trichoderma viride* at 4 g/kg seed followed by soil application of *T. viride* at 1,250 g/ha mixed with 50 kg farm yard manure (FYM) is useful for reducing damping off disease in nursery. Soil application of copper oxychloride at 0.25% was also adjudged as an alternative treatment (NHRDF, 2011). Application of Pendimethalin 30 EC, a pre-emergence herbicide at 2 ml/l at the time of sowing seed effectively control weed population in onion nursery compared to other herbicide sprays (DOGR, 2012).

Seed treatment experiments have been undertaken to improve germination. Solid matrix priming and halo priming with 0.3% KNO or coating with Royalflo could enhance the field emergence with more than 75% germination in seed stored for nine months (IARI, 2010). The seed treatment with glycine betaine (2.5 and 5%) increased yield by 14-19%; whereas, the foliar spray with glycine betaine (2.5 and 5%) increased yield by 12-18% (IIHR, 2010).

Seed treatment with vermiwash has been recommended by University of Agricultural Sciences, Dharwad, Karnataka (Jawadagi *et al.*, 2008) as freshly harvested onion seeds treated with vermiwash recorded significantly higher germination (80.6%), numerically high growth rate index (19.3), shoot length (8.5 cm) and seedling dry matter accumulation (22.3 mg). Coating of onion seed with DAP (30 g/kg seed) + Borax (0.1 g/kg seed) + Carbendazim (3 g/kg seed) resulted in 40% higher bulb yield. During *kharif* season, Karanj leaf powder (500 g/kg seed) is used for higher seed germination (NHRDF, 2011). Gypsum in combination with cow dung or clay or neem or vermicompost powders (1:1 v/v) was used for pelleting of onion seeds. However, germination of pelleted seeds was found to be at par with that of non-pelleted seeds (IIHR, 2010).

Transplanting and crop geometry: About 45-50 days old nursery seedlings becomes ready for transplanting in *rabi* season and in 35-40 days in *kharif.* Maiti and Sen (1974) found that partial trimming of onion seedlings at the time of transplanting augmented the stand of crop and increased the size of bulb. Similar results were also obtained by Rathore and Kumar (1974). Generally, the uprooted seedlings are cut one third from the top. The seedlings are dipped in solution of Carbosulfan (2 ml/l) and Carbendazim (1.5 g/l) for two hours and gently pressed in the soil. For proper growth of seedlings ample nutrition is a predisposing factor. Thus, crop geometry plays a vital role to ensure optimum crop density in the field. In *rabi* season the transplanting in flat beds (2 x 3 m) at 10 cm plant to plant spacing with 15 cm row to row spacing is recommended. In *kharif* the crop geometry of 12 rows at 10 cm distance on broad raised bed of 15 cm height and 120 cm width is recommended (Lawande, 2011). At University of Agriculture Sciences, Dharwad, Karnataka it was revealed that maximum plant height and leaf length was recorded with 15 cm x 7.5 cm spacing followed by 15x10 cm spacing in *cv.* Bellary red (Jawadagi *et al.*, 2012). Bulb yield, net returns and B:C ratio were maximum when the crop planted at 15 cm x 10 cm spacing was nourished with 12.50 t/ha FYM + 2 t/ha vermicompost + 5 kg/ha biofertilizers.

Direct Seeding

Onion can also be grown by direct seeding. Around 12 to 15 kg/ha seed is sown by broadcasting in beds 30 cm apart. The experiments conducted at DOGR revealed that sowing seed in lines manually or with seed drill produced higher yield than broadcasting of seeds. However, seed drills used for direct sowing of onion in India lack precision and their accuracy mostly depends on the skill of person who is performing sowing operations. The Central Institute Agricultural Engineering, Bhopal has imported pneumatic seed drill from Italy. This seed drill is useful for direct sowing of all types of vegetables particularly onion, okra, carrot etc. This versatile and multipurpose machine can be fitted with as many seeding units as needed to meet the specific requirements of the farmers and equipped with everything necessary to handle all the different types of seed. Results of experiment on direct seeding of onion with pneumatic seed drill revealed that among the various sowing methods, the highest bulb size (polar and equatorial diameter), more per cent of A grade bulbs and less number of doubles were researched in direct sown plot using pneumatic seed drill. The highest marketable bulb yield was research in transplanting method only. The less bulb yield in pneumatic seed drilled plots may be due lower seedlings population and crop stand. However, low seed rate, easy sowing, saving in sowing time and early maturity of onion were observed in pneumatic seed drill machine (Sankar *et al.*, 2011).

Sets Planting

Onion production through sets is an innovative technology for *kharif* season where planting coincides with heavy showers, and nursery raising in May is difficult due to hot and humid conditions. In some parts of Gujarat, Maharashtra and Rajasthan, onion is grown in *kharif* by sets to get early crop (Pandey and Singh, 1993). Sets are small size onions produced by allowing the seedlings to mature in the nursery bed as such instead of transplanting them. Seed sowing is done by end of January or February and small bulbs are harvested in the month of April - May. It has been reported that seed sowing in January with 50 g seed/m^2 gave maximum quality of sets. The topped and graded sets are stored in hessian cloth bags or in shallow baskets or in racks in layer not more than 8 cm deep. Ten quintals of sets of 1.5 to 2.0 cm diameter are enough for one hectare planting. But higher yield and net returns were obtained with 2.0-2.5 cm size of sets (Pandey *et al.*, 1990). The closer distance of planting (15x10 cm) was found to be more beneficial with regard to marketable bulb yield, net income, cost : benefit ratio and cost of cultivation (Singh and Singh, 2002). Planting of sets on loamy sand soil by flat system and ridge and furrow system produced an average bulb yields of 132 and 120 q/ha, respectively, compared to 96 q/ha in broad bed system (Sharma *et al.*, 2003). Sets have a shorter growing season than plants from seeds and transplants, and therefore can be exploited when a rapid or early season production is required.

Nutrient Management

An onion crop of bulb yields 35 t/ha removes approximately 120 kg nitrogen, 50 kg phosphorus and 160 kg potash (Tandon, 1987). However, the experiments carried out at Rajgurunagar by DOGR showed that onion crop removes about 90-95 kg N, 30-35 kg of P_2O_5 and 50-55 kg of K_2O to produce 40 t onion bulbs/ha (DOGR, 2012). In addition to NPK, sulphur is also a plant nutrient important for onion crop for improving yield and the pungency of bulbs. Sulphur is absorbed in the form of sulfate ions (SO_4^{2-}). Leaf tissue sulphur level of 0.3 to 0.5% is required during active vegetative growth stage (20-45 DAT), whereas 0.2-0.3% during bulb initiation to development stages (45-75 DAT).

It is reported that application of FYM at 20t/ha + Neem cake at 1 t/ha + S at 20 kg/ha + NPK at 50:50:50 kg/ha as basal application and spray of polyfeed at 1% at 30 and 45 DAP and Multi K at 1% at 60 and 70 DAP was useful for higher bulb yield (NHRDF, 2011). However, DOGR results showed that application of 75% recommended dose of fertilizer (RDF), FYM (5 t), poultry manure (2.5 t) and vermicompost (2.5 t)/ ha gave marketable bulb yield, nutrient content and uptake equal to that of 100% RDF (150:50:80:50 kg NPKS/ha) + 20 t FYM/ha or 100% RDF alone (DOGR, 2012). Based on these results, nitrogen 110 kg/ha in three splits i.e. at the time of planting and 30 and 45 DAP with basal application of phosphorus

(40 kg/ha), potash (60 kg/ha) and sulphur (40 kg/ha) has been recommended (AINRPOG, 2013). Soil application of sulphur beyond 20 kg/ha to onion successively for two years increased the soil available sulphur levels slightly over the initial sulphur level (Thangasamy *et al.*, 2013).

Supplementation of chemical fertilizers with biofertilizers proved beneficial for onion crop (Yogita and Ram, 2012). The maximum plant height, number of leaves, neck thickness, bulb diameter, bulb weight, number of scales and yield and minimum number of days required for bulb formation and number of days taken to maturity were recorded with the application of 100 kg N + 50 kg P + 70 kg K/ha + 2 kg/ha Azotobacter + 1.9 kg/ha VAM. Use of biofertilizers *viz. Azospirillum* and *Azotobacter* increased the growth and yield as compared to corresponding control (Sharma *et al.*, 2010).

To enhance the quality of onion bulbs, the application of plant hormones was evaluated at Anand Agricultural University, Gujarat (Patel *et al.*, 2010). The application of GA3 50 mg/l as root dipping followed by foliar spray significantly increased volume of bulb, equatorial and polar diameter of bulb as well as bulb yield. Use of cytozyme at 0.2% as root dip before transplanting followed by foliar sprays (0.2%) at 15, 45 and 75 days after transplanting has been standardized for higher yield in onion (NHRDF, 2011). Root dipping treatment of NAA 100 mg/l was found effective to reduce the physiological loss of weight, spoilage loss and finally total loss as compared to control.

Organic farming has been found to increase the soil fertility (Subbarao *et al.*, 2011). The use of green manuring with crops like sesbania, cowpea, berseem, wild indigo, green gram, black gram, dhaincha etc. has been advocated by Subbarao *et al.* (2011). Among the various organic growth stimulants *viz.* Panchgavya, Dashparni, Amrutparni, Vermiwash, Seeweed extract, EM Solution, Humic acid, Bio Potash and microbial extract, applied under organic production system, it was concluded that foliar application of Panchagavya (5%) at 30, 45 and 60 days after planting improved the marketable bulb yield in onion (20.2 t/ha) (DOGR, 2011, 2012).

Irrigation and Fertigation

Irrigation requirement of onion depends on the season, soil type, method of irrigation and age of the crop. Onion being a shallow rooted crop needs frequent light irrigation to maintain optimum soil moisture for proper growth and development. For crop establishment, irrigating field 8 hours before transplanting is essential (NHRDF, 2011). Water deficit at crucial growth stages of crop reduces productivity. Studies carried out at Bangalore indicated that maintenance of soil water potential of – 0.85 bar or less either during pre-bulb development (20-60 days after transplanting) or bulb development stages (60-110 days after transplanting) significantly reduced onion bulb yield, and bulb development stage was found to be more sensitive to moisture stress than pre-bulb development stage (Hegde, 1986). According to Saha *et al.* (1997) for optimum exploitation of the yield potential of Taherpuri onion, with maximum efficiency of irrigation water use, 10 to 20% depletion of field capacity moisture might be the most suitable criteria for irrigation. Irrigation at 0.55 atmospheric tension at 6-8 day intervals was found to give the highest yield (199 q/ha) in *cv.* Sukhsagar at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur (Deb *et al.*, 2009). In *cv.* Telagi Red significantly higher bulb yield (54.91 t/ha), number of leaves, leaf area, LAI and neck girth per plant and equatorial diameter, polar diameter and bulb weight was recorded when field was irrigated at one day interval at 100% PE at University of Agricultural Sciences, Dharwad (Bagali *et al.*, 2012).

Several research workers reported that through micro-irrigation higher crop yields can be obtained along with considerable saving in irrigation water (Bhonde *et al.*, 2003, Sankar *et al.*, 2008). Micro-irrigation likes drip and sprinklers have been successfully tried in onion by DOGR. Drip irrigation method produced significantly higher marketable bulb yield than other methods of irrigation. There was around 30% water saving in drip irrigation system as compared with surface system. The highest water-use efficiency (770 kg/ha cm) and minimum storage losses were recorded in drip irrigation system followed by sprinkler irrigation (386.5 kg/ha cm) and the lowest in the surface irrigation (252.5 kg/ha cm). The highest B:C ratio was found in drip irrigation which was 1.98 followed by surface irrigation (1.35) (Tripathi *et al.*, 2010). To maximize the fertilizers use efficiency in onion, the drip fertigation with combined application of organic manures (FYM at 7 t/ha, poultry manure at 3.5 t/ha and vermicompost at 3.5 t/ha) along with 80% recommended dose of water soluble fertilizers have been recommended (DOGR, 2012).

Weed Management

Frequent irrigation and fertilizer application to onion crop favour severe crop-weed competition. Onion crop exhibits greater susceptibility to weed competition than most other crops, mainly due to its slow growth at initial stages and inherent characteristics such as short stature, non-branching, sparse foliage and shallow root system. Major monocotyledonous weed flora in onion are *Cynadon dactylon, Echino cluacrosgalli, E. colacolonum, Sorghum halpense* and *Digitariao bsendens* (Vashi *et al.*, 2010). Whereas the major dicotyledonous weeds in onion are *Phyllanthus maderaspatien, Ephorbia hirta, Amaranthus viridis, Digera arvensis, Trianthem aportulacastrum, Convolvulus arvensis* and *Physalis minima.* Sinha *et al.* (1999) recorded 33 weed species in an onion field at Patna, Bihar and among those, *Cyperus rotundus* and *Cynodon dactylon* were the most prominent weeds that limited the bulb production. Dicotyledonous weed numbers were found to increase with advancement in crop age in a sandy loam soil of Varanasi (Singh and Singh, 1994).

The critical period of crop-weed competition in onion occurred from 45 to 90 days after transplanting (Sankar *et al.*, 2011). Because of labour scarcity, chemical control of weeds along with cultural methods is inevitable. Singh *et al.*, (1991) reported that combined application of fluchloralin@1.25-2.50 kg/ha incorporated in soil 4 days before transplanting followed by pendimethalin at 1.25-2.50 kg/ha applied 1 day after transplanting in addition to one hoeing gave effective control of weeds in onion and resulted in higher bulb yield in a sandy loam soil. Application of pendimethalin at 0.75 kg/ha at pre-emergence stage and at 30 days after transplanting has also been found promising for weed control in onion in some other studies (Pandey *et al.*, 1991; IARI, 2010).

A field experiment with *kharif* onion (*cv.* Bellary Red) on vertisols of Karnataka revealed that pre-emergence application of pendimethalin (1.0 kg/ha) +

hand weeding at 45 days after sowing resulted in highest weed control efficacy (93.5%), bulb yield (13.16 t/ha), benefit: cost ratio (4.87) and the lowest weed index (11.8%) (Nadagouda *et al.*, 1996). According to Saikia *et al.* (1997) maximum cost-benefit ratio (1:1.27) was obtained with fluchloralin (1.0 kg/ha) + hand weeding. However, Singh *et al.* (1997) reported soil application of Pendimethalin at 1.0 kg a.i./ha + 1 manual weeding at 60 days after transplanting as the most economical with a cost benefit ratio of 2:3.1.

Abdallah (1998) reported that if well prepared and pre-irrigated onion seedbed plots are covered with 50 µm-thick transparent polyethylene mulch for 6 weeks prior to seed sowing, it would result in the lowest number and weight of weeds/m^2 and higher seedling emergence. Pre-emergence application of Pendimethalin, Metolachlor and Oxyfluorfen at 1.0, 0.75 and 0.15 kg/ha and each supplemented with one hand weeding at 35 days after transplanting was observed significantly superior over the single application of these herbicides at higher rates in reducing weed dry matter and in enhancing bulb yield of onion (Kolhe, 2001). It was observed at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur that hand weeding at 40 days after transplanting along with application of quizalofop-ethyl 5% EC at 2.5 ml/l of water at 20 DAP significantly reduced weed density (25.5) and dry weight (55.3 g) of weed compared to other treatments. It also resulted in the highest bulb diameter (4.09 cm), bulb weight (13.42 kg) and bulb yield (335.64 q/ha) in *cv.* Arka Kalyan (Yumnam *et al.*, 2009). NHRDF (2011) has recommended the use of rice straw mulch + pendimethalin at 3.5 l/ha at 3DAP for better weed control and higher yield of onion during *rabi* season and in case of its non-availability, wheat straw mulch + Oxyfluorfen at 0.15 kg a.i./ha could also be used. However, DOGR (2012) recommended application of Oxyflurofen 23.5% EC at 1.5ml/l before planting and one hand weeding at 40-60 days after transplanting for good weed control efficiency (73.6 %), higher marketable bulb yield (36.1 t/ha) and the highest B:C ratio (2.54).

Crop sequence

Crop sequences vary depending upon the agro-climatic conditions of the particular location. Normally cauliflower, aster, tomato, potato, bajra, wheat and groundnut are good preceding crops for onion because they require much organic matter in the soil. In western Maharashtra, aster - onion, marigold - onion, groundnut - onion, bajra - onion, onion - wheat, potato - onion, and cucumber - onion sequences are popularly followed among farmers. Crop rotation of egg plant as preceding crop followed by onion as succeeding crop recorded the maximum number of micro-organisms in the onion *rhizosphere* whereas the minimum numbers of bacteria, actinomycetes and other microorganisms were observed in monoculture (Rankev and Surlekov, 1976). Vetrivelkalai and Subramanian (2006) studied the population dynamics of seven plant parasitic nematodes under onion based cropping sequences in Coimbatore, Tamil Nadu. The results revealed that in onion - maize - onion cropping sequence, the populations of *R. reniformis* and *P. delattrei* were increased whereas in onion - tomato - okra cropping sequence, the populations of *H. dihystera*, *H. seinhorsti* and *M. incognita* were increased.

Arya and Bakashi (1999) conducted an experiment at Palampur to find out a suitable onion based cropping sequence along with traditional cropping systems. The results revealed that onion cultivation is more profitable when okra and radish form one of the component vegetables in the vegetable sequences. The crop sequences consisting of aubergine - Chinese cabbage - onion and okra – radish - onion gave significantly higher gross returns than other sequences. The same crop sequences also produced the highest net returns and benefit: cost ratio in Himachal Pradesh. Groundnut - potato - onion cropping system was the best crop sequence with higher yield, more remunerative and land use efficiency (90%) in Punjab (Roy *et al.*, 1999).

Studies conducted at DOGR, Rajgurunagar revealed that among the various cropping sequences evaluated, soyabean in *kharif* season followed by onion in *rabi* season was the best under western Maharashtra conditions in terms of yield, soil health and cost:benefit ratio. There was a tremendous improvement in physical and chemical properties of soil in legume based cropping sequences particularly soybean followed by *rabi* onion and groundnut followed by late *kharif* onion (Sankar *et al.*, 2014). However, growing soybean in *kharif* followed by onion in *rabi* was more remunerative and cost effective than other sequences (DOGR, 2012).

Intercropping

Sugarcane based intercropping with onion has been suggested (NRCOG, 2004). Onion is very much suited to grow as an intercrop in sugarcane under paired row planting system during winter season (November - December planting). Since this crop is shallow rooted bulb forming vegetable having low canopy, it does not compete with deep-rooted long duration crop like sugarcane. Sugarcane-onion intercropping is a common practice in some pockets of Haryana, Maharashtra and Tamil Nadu. Singh (1996) reported that cane equivalent yield and net returns were high when sugarcane planted in autumn was intercropped with onions.

In Karnataka, onion is grown as an intercrop with chilli or cotton. Chilli intercropped with one row of multiplier onion *cv.* Co 2 recorded the highest yield of chilli pods and more net income per unit area per unit time compared to monoculture (Elangovan *et al.*, 1985; Dodamani *et al.*, 1993). Intercropping of onion with tomato decreased the level of thrips infestation by 79-85% and marketable yield increased by 104 to 284% (Afifi and Haydar, 1990). Khurana and Bhatia (1991) reported higher net returns in potato *cv.* Kufri Badshah intercropped with onion *cv.* Hisar-2 than fennel crop. Kothari *et al.* (2000) reported that mint (*cv.* Hy-77) intercropped with one, two and three rows of onion (*cv.* Nasik 58) increased the net return, land utilization efficiency, improved soil moisture (0-15 cm) and utilization of solar radiation than sole cropping. Ibrahim *et al.* (2005) reported the highest intercrop yield when sugar beet plants were arranged in ridges at 60 cm apart, and with distance of 25 cm between sugar beet and onion. Mollah *et al.* (2007) reported the highest groundnut equivalent yield and benefit:cost ratio from groundnut was intercropped with two rows of onion or garlic.

Farm Mechanization

The shortage of labour at the crucial time and increasing labour cost make onion mechanization inevitable. This intervention is mainly solicited in labour intensive work *viz.*, sowing, transplanting, harvesting etc. Direct seed sowing with the local and pneumatic seed drill machine was compared with manual direct seed sowing (broadcasting) and seedling transplanting methods (DOGR, 2013). Among various direct sowing methods, bigger bulbs, more A grade bulbs and fewer double bulbs were observed in sowing using pneumatic seed drill. However, transplanting method of onion production recorded the highest marketable yield, which was significantly higher over the direct sowing with pneumatic seed drill. But low seed rate, easy sowing, saving in time and early maturity of onion were observed in sowing with pneumatic seed drill. The lowest marketable yield was observed in Poona seed drill followed by manual sowing (broadcasting) method.

A six-row tractor operated onion transplanter for flatbed has been designed and fabricated (IIHR, 2010). The six roller wheels press the root of the seedlings in soil and shovels cover the roots with soil. The row spacing in the present prototype is 15 cm and seedling spacing is 10 cm. The expected working speed is 1 km/hour and field capacity is 0.8 ha/day. Manual onion harvesting is also full of drudgery and the mechanization is essentially needed. Prototype of onion digger with length 1.2 m, speed ratio 1.25:1 and slope of the elevator 15 degrees, was found to have digging efficiency 97.7%, separation index 79.1%, bulb damage 3.5%, fuel consumption 4.1 l/ha (12.81 l/ha) and draft 10.78 kN (Khura *et al.*, 2011). Onion detopper was designed and developed at Haryana Agricultural University, Hissar to facilitate the digging and top removal (Rani and Srivastava, 2012). The onion bulbs were fed through a chute type feeding unit to the belt conveyor moving at a speed of 0.53 m/s which ensures uniform transport of the bulbs to an oscillating conveyor. The cutter was provided at the downward side of the oscillating conveyor. The speed of the cutter could be varied and output capacity was 300 kg/hour with the de-topping efficiency of 79%. The belt conveyor had two rollers and an end-less conveyor belt.

For mechanical extraction of onion seeds, experiments were conducted with spike tooth extraction mechanism in a laboratory test set-up (IARI, 2010). The mechanism gave an extraction efficiency of 99% and cleaning efficiency of 97%. The seed loss ranged between 2.2% and 3.1% at cylinder speeds of 3-5 m/s. The costs of seed extraction by mechanical onion seed extractor and manual/conventional method were Rs. 1,800 and Rs. 9,000 per tonne of onion umbels, respectively. The break-even point for seed extractor was 78.77 hours with 31% of annual utility. The payback period of seed extractor was 2.4 years.

Grading of bulbs helps to improve the marketability of the produce. However, hand grading is an expensive operation. To reduce the cost of grading and increase the precision, two onion graders *viz.* manually operated and motorized graders were designed and evaluated by DOGR (Tripathi and Lawande, 2009). These have increased efficiency of 5 and 20 times, respectively, over hand grading. The precision of grading achieved by graders is 98% against 50% in hand grading. The capacity of manual grader is 5 quintals per person per hour with 90% accuracy. The capacity of motorized grader is two tons per hour with 90% accuracy.

Peeling of onion is essential to prepare different processed products *viz.* dehydrated onions, onion powder, onion flakes, onion salt, onion rings, and pickled and canned onions. Onion peeling machine would enhance efficiency of the processing. Central Institute of Agricultural Engineering, Bhopal has developed a batch type multiplier onion peeler (Naik *et al.*, 2007). The multiplier onion needs to have the ends cut with a sharp knife and soaked in clean water for a period of 10 minutes to assist the loosening of peel followed by air drying for 1-2 minutes to remove the surface water. With 92% peeling, and unpeeled and damaged percentage being 6% and 2%, respectively, the capacity of the peeler was found 50-60 kg/h.

The adoption of above mentioned machinery, however, remains to be seen at farmers' fields, because of high initial costs and utility restricted mainly to onion crop.

Crop Protection

Onion is reported to be infected by 29 fungal, four viral and four bacterial pathogens in India. (Gupta *et al.*, 1994). Diseases such as Anthracnose, Purple Blotch and *Stemphylium* Blight cause extensive crop losses and are important throughout the onion producing areas of the country (Anon, 1986). Pink root and *Fusarium* basal rot also have significant impact on onion yield reduction in the country. Iris yellow spot and Onion yellow dwarf viruses are major viruses common and prevalent in major onion growing regions of the country. There are a few diseases of local importance such as downy mildew in temperate zones *viz.*, Jammu and Kashmir and Uttarakhand.

These diseases are responsible for production and storage losses up to 50% or more annually depending upon the location, environment, cultivar and pathogen involved (Srinivas and Lawande, 2007). The amount of economic losses due to diseases varies significantly across three seasons. *Kharif* onion suffers heavily and losses reach as high as 50-60%, late *kharif* is comparatively safe, whereas *rabi* crop losses reach up to 20-30%. Apart from causing direct production losses, these pathogens significantly reduce marketable quality.

Onion is attacked by many insect pests also, which cause damage to leaves, bulbs, flowers and developing seed. Among these thrips and mites are the most damaging, which besides causing direct damage, also act as vectors of various viruses. No reliable source of host resistance in Indian short day onions against major diseases is recorded or reported. It makes imperative to resort only to chemical method of disease control. The symptoms caused and the control measures recommended (Sankar *et al.*, 2014) to control the diseases and pests of onion are given in Table 3.

Postharvest Handling and Storage

Post-harvest management is a crucial operation in the production chain. Although, the pre-harvest cultural practices such as fertilizer application, irrigation etc. have profound role on storage life of bulbs, these factors cannot be managed easily. Thus, proper post-harvest management practices become imperative. The studies revealed that post-harvest losses can range from 45-50% if proper care of the harvested produce is not taken. These losses mainly consist of physiological weight loss (20-25%), sprouting (8-10%) and decay (10-12%) (Gopal, 2014). The estimation of seasonal variation in storage losses revealed that the *kharif* onions were more prone to losses than late *kharif* and *rabi* seasons produce. The total losses which include physiological loss of weight, rotting and sprouting reached almost 70% in *kharif* after three months storage (DOGR, 2013). The light red varieties have more storability than dark red and white bulb varieties (Tripathi and Lawande, 2010). Besides, varietal difference in storability, the losses were also related with bulb size, neck thickness and neck length. A significant reduction in storage losses was observed when the last irrigation was applied five days before harvesting over irrigation applied just before harvesting (Sharma *et al.*, 2007). The crop grown with drip irrigation was reported to have significantly lower losses than the crop grown with surface irrigation (Tripathi *et al.*, 2010). Also, even slight damage to the dry outer scales may hasten loss of water during storage (Sidhu, 2008).

Curing is an important post-harvest management operation which decides the fate of storage. The windrow method of field curing for 3-5 days followed by shade curing for 7 to 10 days has been recommended. The curing of bulbs under poly-tunnel in *kharif* season and pits in *rabi* season was found effective in reduction of losses. Artificial curing of bulbs in curing chamber with full load at 35°C and airflow velocity of 3.2 m/s cured the bulb efficiently. These cured bulbs performed superior in storage as compared to curing under ambient condition during *kharif* season (NHRDF, 2011).

Pre-harvest application of isopropyl–N (3-chlorophenyl) carbamate (CIPC) (2%) at 75 days after planting has been found to reduce sprouting significantly in *kharif* onion varieties *viz.* Bhima Raj and Bhima Red after three months of storage (DOGR, 2012, 2013). However, its application in *rabi* crop was ineffective. Further, post-harvest application of CIPC (hot fogging) could not restrict the sprouting (DOGR, 2012). The gamma-irradiation of some varieties revealed that it could effectively check the sprouting and rotting in all onion varieties (Tripathi *et al.*, 2011). However, no significant effect was observed on weight loss and black mould. It was observed that sulphur fumigation significantly reduced the black mould infestation.

Table 3: Important onion pests and diseases, their symptoms and control measures

Category	Pest	Symptoms	Control measures
Insect	Thrips (*Thrips tabaci*)	1. Thrips infestation at the early stage (transplanting to 45 days) can be identified by curling and twisting of leaves 2. Typical symptoms are the presence of white or silvery patches on leaves 3. In severe infestation, whole plant looks blemished and turns white.	1. Planting of two rows of maize or one outer row of maize and one inner row of wheat as a barrier crop surrounding onion crop (250 m^2) at least 30 days prior to transplanting helps block the movement of adult thrips 2. Foliar spray of insecticides like Profenofos @ 0.1%, Carbosulfan (0.2%) or Fipronil (0.1%) depending upon the severity of infestation
	Eriophyid mite	1. Leaves do not open completely. Whole plant shows curling. 2. Yellow mottling is seen mostly on the edges of the leaves.	1. Foliar spray of Dicofol (0.2%) or sulphur @0.05% after 15 days interval, if necessary.
Fungal Disease	Purple bloch (*Alternaria porri*)	1. Initially small, elliptical lesions or spots that often turn purplish-brown which are surrounded by chlorotic margin. 2. If the spots enlarge, chlorotic margin extend above and below the actual lesion. Lesions usually girdle leaves, causing them to fall over. Lesions may also start at the tips of older leaves.	Foliar spray of Mancozeb @ 0.25% / Tricyclozole @ 0.1% / Hexoconazole @ 0.1% /Propiconazole @ 0.1% at 10-15 days intervals from 30 days after transplanting or as soon as disease appears
	Stemphylium	1. Small yellow to orange flecks or streaks develop in	Foliar spray of Mancozeb @ 0.25% / Tricyclozole

	blight (*Stemphylium vesicarium*)	the middle of the leaf which soon enlarge into elongated, spindle shaped to ovate diffused spots surrounded by characteristic pinkish margin. 2. The spots progress from tip to the base of the leaves, blighting the leaves and gradually the entire foliage.	@ 0.1% / Hexoconazole @ 0.1% /Propiconazole @ 0.1% at 10-15 days interval from 30 days after transplanting or as soon as disease appears
	Anthracnose/ Twister Disease (*Colletotrichum gleosporiodes*)	1. The characteristic symptoms are curling, twisting, chlorosis of leaves, and abnormal elongation of the neck (false stem). 2. Initially pale yellow water soaked oval sunken lesions appear on leaf blades. Numerous black coloured slightly raised structures are produced in the central portion, which may be arranged in concentric rings. The affected leaves shrivel, droop down and finally wither.	1. Planting on raised beds 2. Avoid water logging 3. Foliar Spray of Mancozeb @ 0.25% 4. Soil treatment with Benomyl @ 0.2%
	Damping off (*Pythium* spp, *Fusarium* spp. and *Rhizoctonia solani*)	1. Seedlings topple over after they emerge from the soil. It usually occurs at or below the ground level and infected tissues appear soft and water soaked	1. Planting onion on the raised beds 2. Seed treatment with Thiram or Captan @ 0.3%. 3. Drenching the nursery beds with Captan or Thiram @ 0.2% or Carbendazim @ 0.1% or Copper oxychloride @ 0.3%
Viral disease	Irish Yellow Spot Virus (IYSV)	Straw-coloured, dry, tan, spindle or diamond-shaped lesions, with or without distinct green centers with yellow or tan borders on leaves. The symptoms are more pronounced on flower stalks. Infected leaves	1. Plant high quality transplants free from thrips and Iris yellow spot virus. 2. Practice three years or longer rotations between onion crops.

	and stalks lodge during the latter part of the growing season.	3. Eliminate volunteers, culls, and weeds in and around onion fields. 4. Avoid crop stress. 5. Thrips control will reduce virus incidence as thrips are vectors.
Onion yellow dwarf virus (OYDV)	Mild chlorotic stripes to bright yellow stripes, mosaic, curling of leaves and stunted growth	1. Use virus free planting material 2. Use resistant cultivars 3. Aphid control will reduce the incidence which is a vector for OYDV 4. Foliar spray of Profenofos @ 0.1%, Carbosulfan (0.2%) or Fipronil (0.1%) for controlling aphids

At DOGR, a trial was conducted to assess the effect of different storage structures i.e. traditional, bottom ventilated, mud plastered and chain linked storage structures on storage losses. The packing materials *viz.* stakes, hessain cloth bags, netlon bags and plastic crates were compared for packaging. The results revealed that mud plastered top and bottom ventilated storage structure was superior in reduction of losses *i.e.* weight loss, rotting and sprouting over other structures irrespective of packing materials. Among single row structures, low cost bottom ventilated structure was found to be the best in reduction of losses and increase in net profit. Low cost storage model of 5 to 10 t capacity and high cost model of 25 to 50 t capacity with bottom and side ventilation recommended by DOGR have become popular among the farmers (Murkute and Gopal, 2013). Considering minimal storage losses, subsidy is being advanced to these models by different state governments. Cold storage is the most efficient way to restrict physiological weight loss. However, conducive atmosphere for sprouting in cold storages restricts its use.

Processing

Processing is an efficient way to increase shelf life without compromising the freshness and quality. Dehydrated products such as flakes, rings, granules, powder etc. and processed onions like onion in vinegar and brine are the important products being prepared and marketed worldwide. Onion can also be processed into oil, vinegar and wine etc. However, dehydration of onions is the oldest method of producing concentrated product which has longer shelf life when packaged properly, and can be simply reconstituted without any substantial loss of flavour, taste, colour and aroma. Onions are generally dried from an initial moisture content of about 86% (wet basis) to 7% or less for efficient storage and processing (Sarsavadia *et al.*, 1999). Different methods used for dehydration of onion are solar drying, convective air drying, freeze drying, fluidized bed drying, microwave drying, vacuum drying, infra red drying and osmotic dehydration etc. All onion varieties are not suitable for dehydration. Specific characteristics recommended for drying are white flesh, 15-20% total solid content, high pungency, high insoluble solids and low reducing to non-reducing sugars ratio (Mitra *et al.*, 2012). Based on the recovery and quality of red and white onion flakes, cabinet drying method has been recommended (DOGR, 2011). The white onions were found to give higher recovery (11%) than red onions (10%). Sun drying had the disadvantage of scorching and brownish colour due to direct exposure to sun light. Time required for drying is maximum in sun drying followed by solar drying and the minimum for cabinet drying. Cabinet dried onion flakes were found superior for shelf life and in rehydration ratio of flakes as compared to other drying methods.

Bulk trial on white onion dehydration using 50 kg lot indicated that dried onion yield of 9.9% on fresh weight basis could be obtained. Sensory evaluation studies using 9-point hedonic scale revealed that curry prepared from dehydrated onion was acceptable in terms of colour, taste/pungency and texture compared to fresh and rehydrated samples. Storage studies of dried white onion in three different packages, *viz.*, PET jar (100 g), 150 gauge polyethylene pouch and plastic pallet at room temperature showed that at the end of 6 months storage period, samples packed in PET jar and plastic pallet retained original colour, whereas sample packed in polythene pouch developed browning (IIHR, 2010).

Marketing and Export

A number of agencies including producers, commission agents, merchants, wholesalers and cooperatives *etc.* are involved in marketing of onions. The onion bulbs are produced all over India but marketing is well organized only in Maharashtra, Karnataka, Delhi, Gujarat and Rajasthan. In these states, the cooperatives and NAFED are playing significant role in the marketing of onion bulbs. NAFED intervenes in the domestic marketing whenever there is glut in the market and prices reach uneconomical levels. The Agricultural Produce Marketing Committees (APMCs) were established in each state by the respective state governments with a view to regulate the marketing of agricultural produce. The regulation of markets had several positive features such as sale through auction method, reliable weighing, standardized market charges, payment of cash to farmers without undue deductions, dispute settlement mechanism, and reduction in physical losses of produce and availability of several amenities in market yards. Onion bulbs from different places of the country are assembled and distributed through (i) open auction system (Lasalgaon, Chakan, Pune, Mysore, Bellary); (ii) under cover or hatha system (Vashi, Mumbai); (iii) tender system (Mysore, Bellary and Hubli); (iv) open agreement system. Properly graded, well cured and cleaned bulbs should be marketed for fetching better price in the market.

Besides fulfilling the constant demand of domestic population, India exported 18.22 lakh tons of onion worth Rs. 2,294 crores during 2011-12 (NAFED, 2013). About 90% export of onion is from Maharashtra. There is critical shortage in arrivals of onion in the market during November to January. From May to November stored onions are used for domestic as well as export market. November to December *kharif* onion is available in the market, whereas from January to March late *kharif* crop from Maharashtra is available. Export trade from Mumbai and Kandla port mainly to Gulf countries predominantly during November to April coincides with harvest of rainy season and late rainy season crops.

India is the third biggest exporter of onion, next to Netherlands and Spain, in the world and contributes about 12% of the global market. Mainly onion bulbs having dark- and light red colour are exported from India. The major countries importing onion bulbs from India are Malaysia, Bangladesh, Indonesia, Kuwait, Maldives, Mauritius, Nepal, Quatar, Saudi Arabia, Seychelles, Singapore, UAE, UK etc. The specific requirements of export onion are 4-6 cm bulb diameter, light to dark red colour, round shape, strong pungency for gulf markets and South East Asian markets. Whereas for Bangladesh, bulbs of 3-4 cm diameter and having light red and round shape are preferred. Yellow/brown colour bulbs of 7-8 cm diameter and having round or spindle shape are preferred in the European and Japanese markets. Small onions (Agrifound Rose and Bangalore Rose) grown in Karnataka and Andhra Pradesh, and Multiplier onion (Co4 and Co5) grown in Tamil Nadu are exported to Malaysia, Singapore and Gulf countries. Onion is an unique example where market forces have influenced domestication and diversification of the crop largely.

Future Challenges

Although research and development has helped in enhancing production and export of onion, in productivity there is marginal increase. Statistics (Figure 1) indicate that in India production of onion has increased from 47.21 lakh tons in year

2000 to 175.11 lakh tons in 2012 (DES, 2013). This increase, however, has com mainly from increase in area which in 2012 stood at 10.87 lakh ha. Although secon in onion production after China at world level we are far behind in productivit compared to many countries. The average productivity of onion in India now stand at only 16.11 t/ha, which is lower than world average of 18.67 t/ha. The highe productivity of onion has been reported to be 62.50 t/ha in Ireland (DES, 2013 Maharashtra, Karnataka, Gujarat, Bihar, Madhya Pradesh, Rajasthan, Andhr Pradesh and Tamil Nadu are the main onion growing states of India. In genera barring North Eastern states and Kerala, all other states grow onion. Country's 26 area and 29% production alone come from Maharashtra (Figure 2).

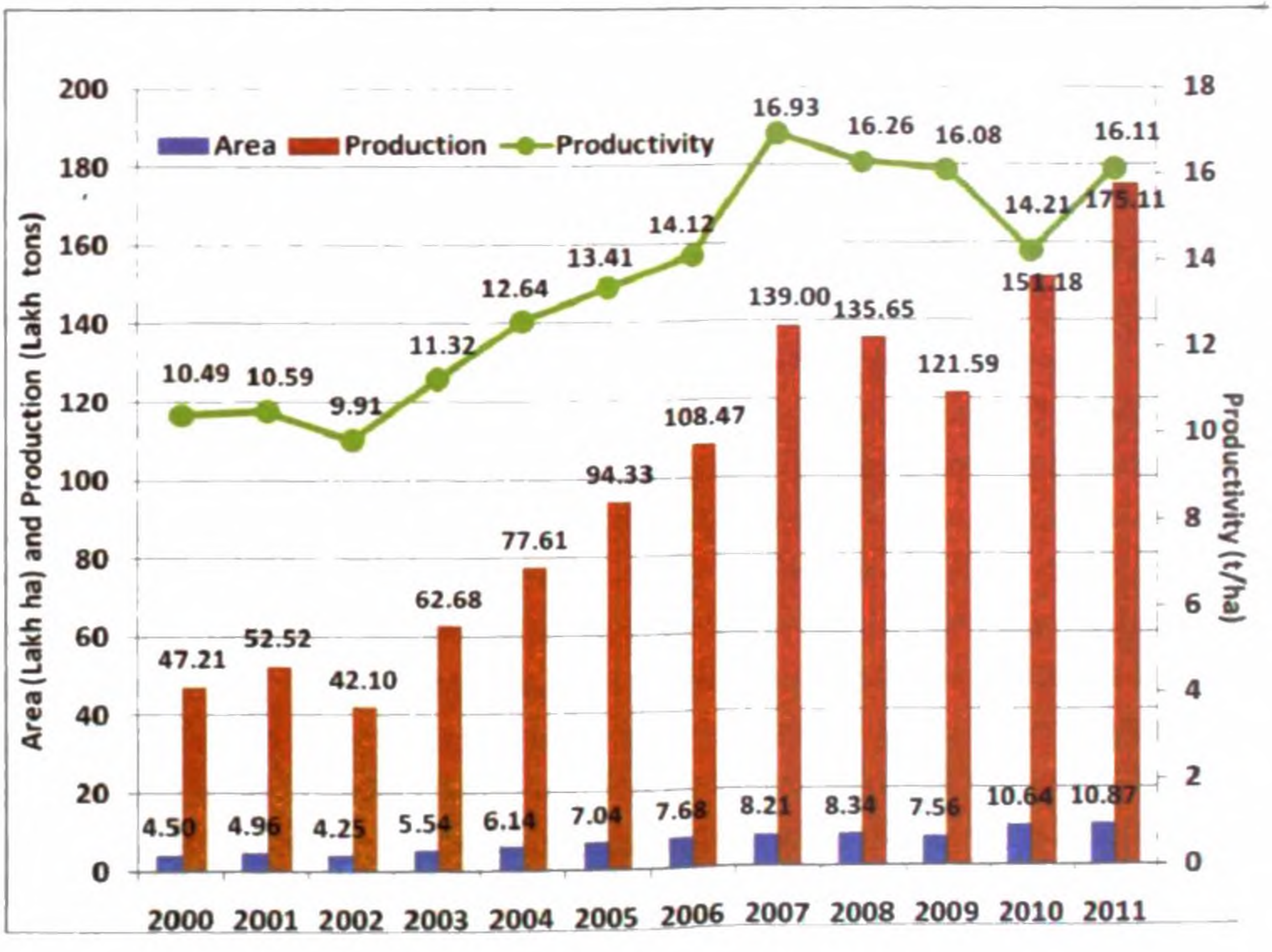

Figure 1: Year-wise area, production and productivity of onion in India.
Source: DES, 2013.

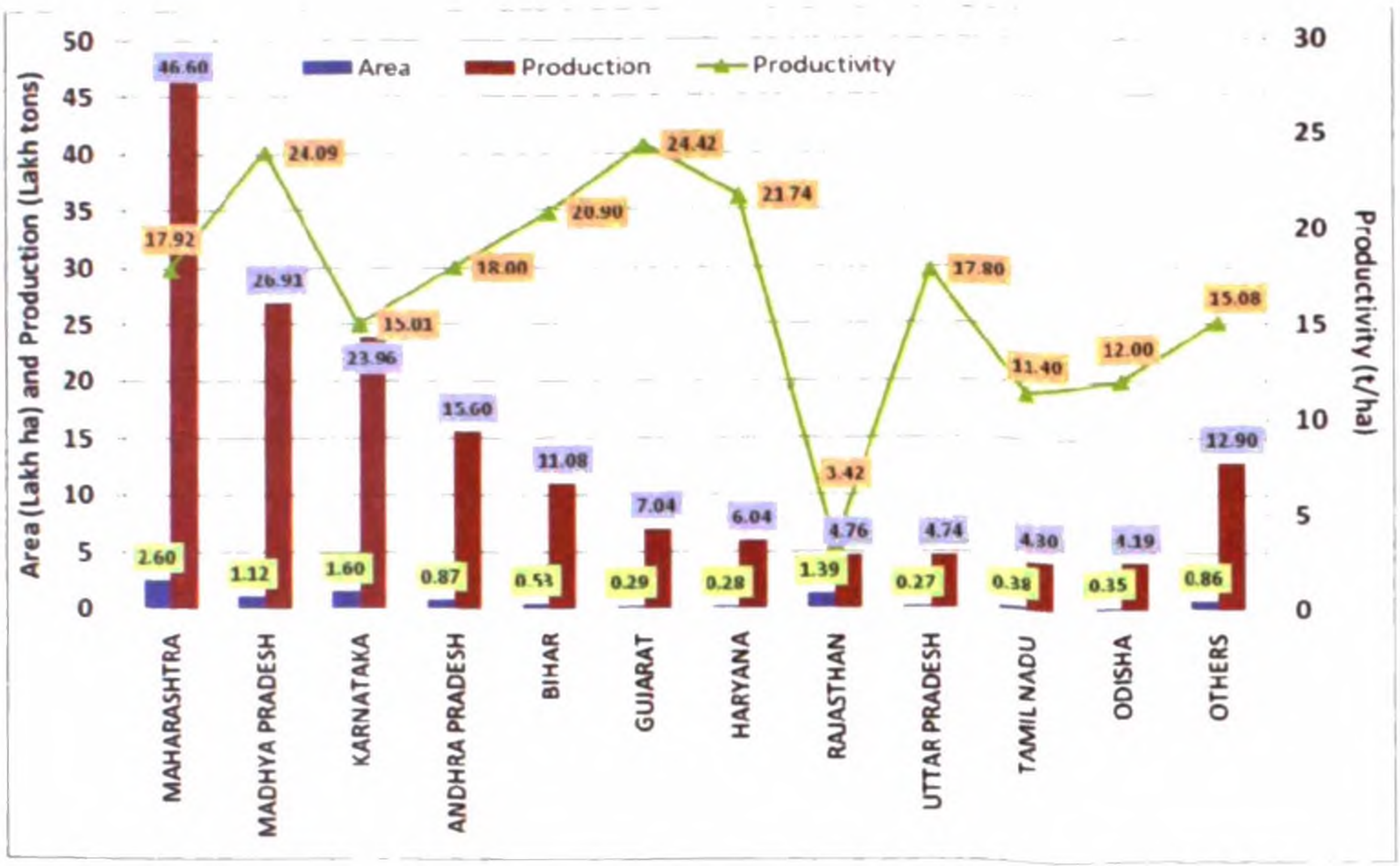

Figure 2: Area, production and productivity of onion in major onion growing states of India (2012-13).

Source: DES, 2013.

The main reasons for low productivity of onion in India are listed below.

1. Inherent low yield potential of short day onion varieties.
2. Non-availability of suitable F1 hybrids.
3. Susceptibility of all cultivars to diseases, pests and abiotic stresses.
4. Tropical climate is more congenial for diseases and pests.
5. Non – availability of genuine seeds of released varieties.
6. Sub – optimal standards of cultivation adopted by farmers.
7. Shortage of irrigation at critical stages.
8. Poor storage capacity of present day varieties and poor storage facilities.
9. *Kharif* crop always pull down country's average productivity.
10. Fluctuation of prices distracts the attitude of farmers towards use of inputs and modern technology.

India is projected to have population of 1.7 billion by 2050, and there is limited possibility to increase the cultivable land. To cater to the requirement of this ever increasing population, keeping per capita consumption, export, processing and losses at existing rate (consumption i.e. 7.83 kg/person/year, export 9%, processing 6.75% and losses 30%; base year 2010-2011), we will require 24.62 million t of onion in 2050 against 19.29 million t in 2013-14. This demands an increase in average productivity from 15.85 to 22.7 t/ha, which is 42.9% higher than that of in 2013-14. Efforts can be made to reduce losses up to 20%, increase export up to 25% and processing up to 15% by 2050. With these targets, we have to increase production from 19.29 to 33.39 million t with productivity of 30.72 t/ha.

Thus, there is need is to explore the innovative measures to improve productivity and stabilize production of onion in India. The following interventions may help to improve the productivity and prospects of onion cultivation in India.

i. Basic research in breeding for resistance, processing qualities and export worthy varieties are lacking. Thrust in these areas can help to improve onion productivity and export.

ii. Biennial nature, high cross-pollination and sharp inbreeding depression in onion are still challenges for breeders using conventional approaches. There is thus an opportunity to use biotechnology, particularly molecular approaches and functional genomics to overcome these problems.

iii. Due to poor maintenance of breeders' stock, many varieties are out of production chain or could not even make entry into the chain. Farmers find easy and economical to produce their own onion seed but due to ignorance of out-crossing they are not able to maintain purity. Due to supply of spurious seed by many seed merchants, the spread of good varieties has been hampered. Thus, there exist opportunity to produce and distribute good quality seed of true-to-type varieties and capture the market of onion seed. Seed multiplying agencies working in public sector need to be sensitized in this regard.

iv. Thrust is required to increase the national storage capacity. Infrastructure facilities need to be created that about 30-40% produce is stored in the cold storages to significantly reduce the post-harvest losses.

Focus should also be to evolve a robust supply chain based on domestic demand, export and a quantum for processing to avoid price fluctuations by harnessing available resources, modern infrastructures, improved technologies and innovative endeavours. Policy makers will have to work hard to provide amicable solutions on pricing which should lead to higher profits to farmers but not at the cost of consumers.

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