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Onion and garlic research in India

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ABSTRACT

Onion and garlic research in India has produced 45 open-pollinated and two F_1 hybrids in onion and approximately 25 varieties in garlic. Red onion is used for domestic consumption and export while the white onion is used mostly for processing. Improvement in garlic has been largely through clonal selection and mutation breeding. Somaclonal variations for development of varieties have not been used till now. Research on biotechnology for crop improvement in onion and garlic in India is in a nascent stage. While research on crop production has seen tremendous improvement, research on organic production and precision farming, good agricultural practices and mechanization needs to be carried out in future. Similarly, studies on plant protection have identified researchable issues for future work. This paper gives a brief overview of onion and garlic research scenario in India and technologies needed to be developed and practised.

Key words : Onion, garlic, improvement, biotechnology

INTRODUCTION

Onion and garlic, members of *Alliaceae* family, are cultivated throughout the world for food, therapeutic and medicinal value. In India, onion and garlic have been under cultivation for the last 5000 years. As per FAO (FAOSTAT, 2010), onion is grown in 0.8 Mha with production of 8.2 MT and productivity of 10.16t/ha, whereas, garlic is grown in 0.015 Mha with production of 0.65 MT and productivity of 4.32 t/ha in India. Maharashtra is the leading state in onion production followed by Uttar Pradesh and Orissa, whereas, Madhya Pradesh is the major garlic producing state, followed by Gujarat and UP (Anon., 2010). India ranks second to China in area and production in both onion and garlic, but ranks 102nd for onion and 74th for garlic in terms of productivity (FAOSTAT, 2010). Production and productivity not only depends upon area and cultural practices but also on genotype and environment of the crop. In India, major area under onion and garlic cultivation is in tropical areas as compared to the high yielding countries where maximum areas under these crops fall under temperate regions. Onion and garlic are both day and temperature sensitive crops and perform very well under temperate conditions. Secondly, most of the farmers in India use their own seed material for cultivation, which is not regulated properly for varietal admixture and consists of a heterogeneous material which reduces productivity. Whereas in other countries, farmers use only well recognized and high performing commercially released varieties for cultivation. India is a traditional grower and exporter of both the crops and it assumes number one position in onion export in the world. Both the commodities are going to continue their importance in trade and India has to remain always in competitive situation. But, be competitive, we need to improve our productivity level by gearing up research and development. In the case of research, a critical analysis of what has been done and what is required is always required for strategic planning.

Onion breeding

Systematic breeding programme was started as early as 1960 at Pimpalgaon Baswant, Nashik and later at IARI, New Delhi. Early varieties developed through selection viz., N-2-4-1 and Pusa Red are still dominating onion production. The programme was further strengthened under a coordinated project by institutes of the Indian Council of Agricultural Research at National Horticultural Research and Development Foundation and State Agricultural Universities (SAUs). As a result, 45 varieties of onion (including two F_1 hybrids and 6 varieties of multiplier onion) have been developed and released. Onion is mainly *rabi* season crop, but it can also be cultivated in *kharif* and late *kharif*. Based on seasonal requirement, varieties have been recommended e.g., in *kharif* season, varieties Baswant–780, N-53, Agrifound Dark Red, Arka Kalyan and Bhima Super; in late *kharif*, varieties Baswant–780, Phule Samarth, Bhima Red and Agrifound Light Red and in *rabi* season, varieties N-2-4-1, Arka Niketan, Agrifound Light Red, Pusa Red, Pusa Madhavi, Bhima Raj, Bhima Red can be cultivated. Bhima Super, Bhima Red and Bhima Raj have the potential to grow in all three seasons, viz., *kharif*, late *kharif* and *rabi* season in Maharashtra. Several white coloured varieties, e.g., Phule Safed, Pusa White Round, Pusa White Flat, Agrifound White, Punjab Selection, Udaipur–102 are also cultivated by farmers.

A comprehensive list of varieties released from various research institutes / universities are furnished in Table1.

Varieties developed by various organizations listed above have been tested at different locations under the All-India Coordinated Vegetable Improvement Project (AICVIP) and based on their performance; these varieties

Table 1. Onion varieties developed by different organizations in India

Sl. No.	Organization	Onion variety	Colour of bulb
1.	Agril. Dept., Maharashtra State	N-2-4-1	Red
		N-53	Red
		N-257-9-1	White
2.	Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra	Baswant-780	Red
		Phule Safed	White
		Phule Swarna	Yellow
		Phule Samarth	Red
3.	Indian Agricultural Research Institute (IARI), New Delhi	Pusa Red	Red
		Pusa White Flat	White
		Pusa White Round	White
		Pusa Ratnar	Red
		Pusa Madhavi	Red
		Early Grano	Yellow
		Brown Spanish (Long day)	Brown
4.	Indian Institute of Horticultural Research (IIHR), Bangalore, Karnataka	Arka Niketan	Red
		Arka Kalyan	Red
		Arka Bindu	Red
		Arka Pragati	Red
		Arka Pitambar	Yellow
		Arka Lalima (F1 hybrid)	Red
		Arka Kirtiman (F1 hybrid)	Red
5.	Haryana Agricultural University (HAU), Hissar	Hissar 2	Red
		HOS-1	Red
6.	National Horticultural Research and Development Foundation (NHRDF), Nashik, Maharashtra	Agrifound Dark Red	Red
		Agrifound Light Red	Red
		Agrifound White	White
		Agrifound Rose	Red
		Agrifound Red (Multiplier)	Red
		L-28	Red
7.	VPKAS, Almora	VL-1 (Long day)	Red
		VL-3 (Long day)	Red
8.	Rajasthan Agricultural University (RAU), Rajasthan	Udaipur 101	Red
		Udaipur 102	White
		Udaipur 103	Red
9.	Chandrashekhar Azad University of Agriculture and Technology (CSAUAT), Kanpur, UP	Kalyanpur Red Round	Red

10.	Punjab Agricultural University (PAU), Ludhiana, Punjab	Punjab Selection	Red
		Punjab Red Round	Red
		Punjab Naroya	Red
		Punjab-48	White
		Punjab White	White
11.	Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu	CO-1, (Multiplier)	Red
		CO-2	Red
		CO-3	Red
		CO-4	Red
		MDU-1	Red
12.	Regional Agricultural Research Station (RARS), Durgapura, Rajasthan	Rajasthan Onion -1	Red
		Aprita (RO-59)	Red
13.	Punjabrao Deshmukh Krishi Viswavidyalya, Akola, Maharashtra	Akola White	White
14.	DOGR, Rajgurunagar	Bhima Raj	Red
		Bhima Super	Red
		Bhima Red	Red

have been recommended for different zones. So far, 20 varieties have been recommended for cultivation under specific agro-climatic zones (Table 2).

Biennial habit of onion, coupled with longer time taken for breeding and difficulties in attaining / maintaining genetic uniformity (due to high degree of natural cross-pollination and rapid inbreeding depression) have made this crop unattractive to breeders for further improvement. Though a number of varieties have been developed in India, there is still enough scope to develop varieties with high total soluble solids (TSS) suitable for dehydration, short-day yellow varieties for export, varieties resistant to diseases and insect pests and suitability in different seasons. Indian varieties pose problems of bolting and doubling of bulbs, especially in the September – October planting. There is a need to develop bolting resistant varieties for this season.

Table 2. Onion varieties recommended through AICRP for release and cultivation

Sl.No.	Variety	Organization	Recommended zones*	Year of identification
1	Punjab Selection	PAU, Ludhiana	IV, VII & VIII	1975
2	Pusa RedI	ARI, N. Delhi	IV, VII, VIII	1975
3	Pusa Ratnar	IARI, N. Delhi	IV & VI	1975
4		S-131	IARI, N. Delhi	- 1977
5	N-257-9-1	Agrl. Dept., M.S.	-	1985
6	N-2-4-1	Agrl. Dept., M.S.	-	1985
7	Line-102	IARI, N. Delhi	I, IV, VI, VII	1987
8	Arka Kalyan	IIHR, Bangalore	IV, VI, VII, VIII	1987
9	Arka Niketan	IIHR, Bangalore	IV,VII, VIII	1987
10	Agrifound Dark Red	NHRDF, Nashik	IV	1987
11	VL-3	VPKAS, Almora	I	1990
12	Agrifound Light Red	NHRDF, Nashik	VI, VIII	1993
13	Punjab Red Round	PAU, Ludhiana	IV	1993
14	PBR-5	PAU, Ludhiana	VI	1997
15	L-28	NHRDF, Nashik	IV & VII	2006
16	HOS-1	HAU, Hissar	VI	2006
17	Bhima Raj	NRCOG, Rajgurunagar	VI	2007
18	Bhima Red	DOGR, Rajgurunagar	VII	2009
19	PKV White	PDKV, Akola	VI	2009
20	RHOR-S1	MPKV, Rahuri	VI, VIII	2009

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

Uniformity in colour, shape and size is also lacking. True breeding lines need to be developed.

Breeding for white onion

Onion varieties for dehydration should be pure white, globose in shape, thin necked, free from greening and moulds, with high pungency, TSS and yield, and, show field tolerance/resistance to diseases and pests. Wider seasonal adaptability is also an important character for continuous supply to industries for dehydration.

Some indigenous as well as exotic onion varieties were evaluated for dehydration ratio by Saimbhi *et al* (1970) who found dry matter to range from 7.4 to 16.2%. White onions are preferred for dehydration purpose and various technical requirements have been mentioned by Anand (1972). Sethi *et al* (1973) reported that for dehydration purposes, globe shaped varieties with 5 – 7.5 cm diameter were preferred, as slicing was easy. Bajaj *et al* (1979) identified cv. Punjab-48 as most suitable for dehydration on account of its TSS (14.6%). Varietal characteristics, storage and drying behaviour of four commercial genotypes were studied by Maini *et al* (1984) and they concluded that Roopali was better-suited both for storage and dehydration. Kalra *et al* (1986) found S-74 to be most suitable, followed by Punjab-48 for dehydration, with TSS 14.3 and 13%, respectively. Raina *et al* (1988) recorded maximum (15.8%) TSS in Texas Yellow, followed by Punjab Selection (13.3%), Udaipur-102 (13.5%) and Punjab-48 (13.4%). Saimbhi and Bal (1996) observed TSS ranging from 14.0 to 16.2% and cultivar PWO-1 was found most suitable for processing. Bhagchandani *et al* (1980) reported Pusa White Flat and Pusa White Round as suitable varieties with the least losses under storage. Storage loss in variety Punjab-48 was studied by Saimbhi and Randhawa (1982) and found losses in storage to be greatest in large bulbs and least in the small ones.

Generally, Indian white onion varieties have low TSS (10-14%), which is not suitable for dehydration. After assessing Indian varieties and land races which do not have high TSS, Jain Food Park Industries, Jalgaon, introduced White Creole, which was further subjected to selection pressure for high TSS and they developed V-12 variety with TSS range of 15-18% (personal communication). Elsewhere in India, attempts were made to develop white onion varieties suitable for different seasons by various research institutes (Table 3).

White lines are required mostly for processing. High TSS (>18%) is the main requirement in these varieties. TSS in any variety is a function of genotype, environment and cultural practices. Long day onion grown under mild climate is high in TSS, whereas, short-day onion maturing under short winters does not develop high TSS. Internationally, long-day and intermediate short-day varieties have been developed mostly from USA, Spain, Israel, Mexico, etc.

Introgression of genes from long-day varieties can help develop high TSS in short- day types. Besides TSS, resistance and greening of outer scales is also a major concern. In processing, the globose shape is preferred as there is less wastage in topping and telling by the machine. Development of globose shape would be a further priority in onion improvement.

Breeding for yellow onion

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

Table 3. Performance of white onion varieties developed in India

Sl. No.	Name of the variety	Source	TSS(%)	Average yield (t/ha)
1.	Pusa White Round	IARI, New Delhi	11.13	30.0 – 32.5
2.	Pusa White Flat	IARI, New Delhi	10.00	32.5 – 35.0
3.	Udaipur 102	RAU, Udaipur	10.06	30.0 – 35.0
4.	Agrifound White	NHRDF, Nashik	10.76	20.0 – 25.0
5.	Phule Safed	MPKV, Rahuri	10.13	25.0 – 30.0
6.	PKV White	PDKV, Akola	09.55	25.0 – 30.0
7.	Gujarat White Onion	JAU, Junagadh	—	30.0 – 32.5
8.	N-257-9-1	Agril. Deptt., M.S.	10.00	25.0 – 30.0
9.	Punjab-48	PAU, Ludhiana	11.00	30.0 – 32.5
10.	V-12	Jain Food Park, Jalgaon	15.00	35.0 – 40.0
11.	Nimar Local	Land Race, M.P.	12.50	25.0 – 30.0
12.	Talaja Local	Land Race, Bhavnagar	12.00	25.0 – 30.0

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* (1988) through original, single-bulb selection from Texas Early Grano 951 through 5 generations of selections. Similarly, "Texas Grano 1030 Y" was developed from F_2 selections of Texas Early Grano 502 x Ben Shemen by Pike *et al* (1988), 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.

Development of hybrids

India is a major onion growing country and more than 30 open-pollinated cultivars have been released for cultivation at the national and state level, besides local cultivars (Lawande, 2005). Statistical evidence indicates that productivity of onion in India is quite low. In order to increase productivity, development and cultivation of F_1 hybrids is a must. F_1 hybrids have been reported to be high-yielders, have uniformity in colour, size and good storage life. Onion breeding was started in the early thirties, based on male sterility found in onion in California during 1925 from the cultivar Italian Red 13-53 (Jones and Emsweller, 1937). Later, hybrid onion seed was produced commercially by utilizing cytoplasmic genetic male sterility (CMS) in USA, an outcome of identification and exploitation of CMS system in onion (Jones and Davis, 1944).

At present, hybrid onion is predominantly used in USA, Canada, UK, The Netherlands, Germany, Israel and Japan and its popularity is increasing in France, Italy, Hungary, Spain, Australia and New Zealand due to higher yield, uniformity, better storage life, availability and exploitation of stable male-sterile lines and the long-term vision of varietal protection. However, no local hybrids are grown in South America, many parts of Africa, Asia, Poland, Spain, Yugoslavia, Czechoslovakia and Greece. Lack of exploitation of onion hybrids in these countries may be due to non-availability of the diverse inbred lines and little effort made for identification of stable male sterile lines with maintainer lines. In India, Sen and Srivastava (1957) attempted, for the first time, to develop F_1 hybrids in onion (as early as in 1948) using exotic male sterile lines and Indian local male stocks but these male sterile lines were unstable under short photoperiods in India. Studies by Joshi and Tandon (1976) and Pal and Singh (1999) showed a good amount of heterosis in onion in India at 84.5% over the better parent, 58.6% over the top parent and 74.5% over the control. For TSS, the hybrid showed 6% heterosis over the top parent. Heterosis for yield, earliness, uniformity in maturity, bulb size and shape, storage quality and dry matter has been reported by some workers (Joshi and Tandon, 1976; Madalgeri and Bojappa 1986). On the other hand, open-pollinated varieties may be equally good, if not superior, to hybrids which may be due to the narrow genetic base of inbred lines involved in F_1 hybrid development (Swarup, 1990; Khar *et al*, 2000). An advantage of 5-10% increase in yield in hybrids is generally not economical considering the technical difficulties encountered in production of hybrids seeds, besides the high cost of seeds. Narrow genetic base of inbred lines involved in developing F_1 hybrids may be one of the major reasons for the low level of heterosis. There can be good control over seed production and distribution as hybrids involve three parents. Some of the male sterile lines developed in India are not stable and the inbred lines developed are not pure. The work gained momentum in the eighties at IIHR (Bangalore), IARI (New Delhi) and MPKV (Rahuri). At IARI, male sterility was found in a commercial variety, Pusa Red (Anon., 1986). Only two hybrids, Arka Kirtiman and Arka Lalima, have been released by IIHR after development of CMS lines along with the maintainer, by Pathak *et al* (1986). Aghora and Pathak (1991) reported heterosis in bulb-yield of upto 28.5% over the best commercial variety in short-day onion, but due to difficulties in getting stable CMS lines further, the work could not gain momentum.

Some of the exotic hybrids perform well during late *kharif* under Indian conditions and yields are almost double that in the Indian varieties at Directorate of Onion and Garlic

Research, but these have very low TSS, storage life and are yellow in colour, which has no consumer preference in India. These can be used to capture the European and Japanese markets where there is a great demand, but it is possible only through a cool chain. However, exotic hybrids are required to be tested at different locations for yield and commercialization. Further, plant quarantine rules need to be followed strictly to check entry of new diseases. Farmers are therefore advised not to grow exotic hybrids in a large scale unless prior tested under Indian conditions. Development of F_1 hybrids in short-day types in India was emphasized 20 years ago and has remained an important area of research. Private seed companies have recently started selling F_1 hybrids. Trials conducted at Directorate of Onion and Garlic Research on exotic F_1 hybrids in yellow type exhibited very good performance in late *kharif* and *rabi* seasons. Of the 90 exotic varieties tested during 2000-2008, more than 20% and higher yield was recorded in 10 varieties during late *kharif* over Bhima Super, and 16 during *rabi* season over N-2-4-1 under Maharashtra conditions (Table 4). Yield increase was recorded upto 60.87% in late *kharif* and 57.41% in *rabi* over the respective checks of best open- pollinated varieties. Further, F_1 hybrids developed under a hybrid network programme at Directorate of Onion and Garlic Research using two CMS lines indicated very high percentage of heterosis over standard checks ranging from 17 to 59% over N 2-4-1, and 11 to 50% over ALR. But, later, instability in male sterile lines became a bottleneck. Some of the male sterile lines introduced are being evaluated for stability and crosses are being made with inbred lines to identify the best combiner.

Yield levels in varieties developed has reached a plateau. Variability in germplasm has also been exhausted. There are two alternatives to create variability: by (i) mutation breeding and (ii) hybridization with exotic varieties. Exotic onions are mostly long-day types. In some of the intermediate-day types, bigger sized bulbs are obtained under Indian conditions, but are unable to flower. Mutation breeding creates variability but results are not predictable. An alternative is to make crosses between long-day or intermediate-day type exotic onions under temperate conditions i.e., in a phytotron or in temperate northern hills. Hybrids, after testing, can be exploited or further selection can be made for desirable characters and inbred lines can be developed for developing hybrids.

Table 4. Performance of exotic hybrids/varieties of onion under the Indian plains (2000-2008)

Exotic onion variety	Late *Kharif* yield (t/ha)	% Increase over Bhima Super	*Rabi* yield (t/ha)	% Yield increase over N-2-4-1
HN 9539	54.03	22.34	—	—
HN 9733	31.13	-29.52	65.90	52.55
HN 9935	36.09	-18.29	68.00	57.41
Hy 3404	57.36	29.89	56.45	30.67
DPS 2023	60.87	37.84	59.80	38.43
Early Supreme White	54.65	23.75	41.50	-3.94
Cougar	56.50	27.95	67.84	57.04
DPS 1008	31.80	-27.99	52.50	21.53
DPS 1009	31.12	-29.54	64.45	49.19
DPS 1024	38.62	-12.55	66.05	52.89
DPS 1031	5.10	-88.45	54.30	25.69
DPS 1034	59.66	35.10	58.60	35.65
DPS 1043	—	—	61.45	42.25
Linda Vista	50.58	14.53	59.59	37.93
Mercedes	47.93	8.53	63.27	46.46
Lexus	59.66	35.10	63.83	47.75
Reforma	37.67	-14.70	66.53	53.99
Gobi	42.22	-4.39	52.67	21.92
Kalahari	53.10	20.23	38.04	-11.94
Rio-Tinto	54.37	23.11	34.52	-20.09
Serengeti	55.87	26.52	50.85	17.71
Arka Kirtiman (C)	—	—	26.90	-37.73
Arka Lalima (C)	25.86	-41.44	26.20	-39.35
Bhima Super (C)	44.16		—	—
N-2-4-1 (C)	—	—	43.20	

Male sterile lines developed at various institutes also need to be tested at different locations for stability and for transfer of trains into the background of the best-selected varieties and genotypes with diverse nature, along with development of maintainer lines. Constant upgradation and improvement of parental lines by reciprocal recurrent selection and introgression of genes from long-day types will elevate the genetic potential of parental lines. Development of 100% homozygous lines through haploidy by anther culture and diploidization is the best option for developing of quality inbred-lines. Training of elite farmers for seed production and making available ample seed of F_1 hybrids at reasonable rates is the need of the day. Besides, unless the potential of F_1 hybrids is proved through frontline demonstrations vis-à-vis farmers' own material and released open-pollinated varieties, hybrids will not take off.

Improvement of garlic

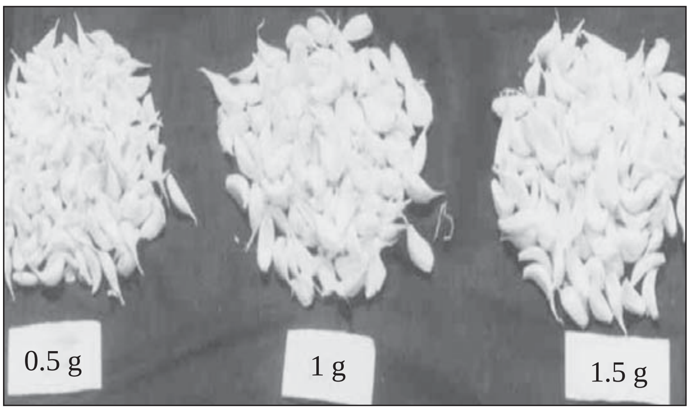
Being an asexually propagated crop, methods of improvement through cross- pollination are not viable in garlic. Most of the varieties developed are through introductions and clonal selection. Based on temperature and day-length response, garlic has been classified as having long-day and short day varieties. It has also been classified as having hard neck and soft neck varieties. Hard-neck varieties bolt and flower but these flowers are usually sterile, while soft-neck varieties do not flower at all. Hard neck varieties cannot be braided for storage whereas softneck varieties can be braided and stored. Hard neck (long- day varieties) is characterized by big bulbs, less number of cloves (10-15), ease of peeling and, generally, have low storage life. Typical examples are Agrifound Parvati and Chinese garlic. Because of big size, their productivity is higher and these fetch a good price in local and international markets. Soft-neck (short-day) varieties are characterized by small bulbs, more number of cloves (20-45), more aroma and are, generally, good storers e.g., Indian garlic varieties G41, G1, G50, G282, etc. On the basis of consumption, area and production statistics, garlic is an important commodity in the Indian market, yet, public or private research on this crop has been less than encouraging. The main reason for this may be its asexual nature which limits breeding methods and area under its cultivation. At the international front, there are a few reports of flowering and seed production, but even now garlic is considered a sexually sterile species. Breeding methods for development of garlic are limited to clonal selection and mutagenesis among conventional methods, and somaclonal variation among biotechnological approaches. In India, most varieties have been developed through clonal selection and one or two through introduction. National Horticultural Research and Development Foundation (NHRDF) has been at the forefront of garlic research (with maximum number of varieties developed under their research programmes), followed by agricultural universities, viz., Gujarat Agricultural University (GAU), Punjab Agricultural University (PAU), MPKV, Rahuri, etc. Most of the varieties developed in these institutes are short-day type and can be grown under tropical and sub tropical climates. Some temperate varieties have also been released at the national level and prominent among them is Agrifound Parvati. Other temperate varieties of significance are VLG-1 (VPKAS, Almora), SKUAG 1 (SKUAST, Srinagar), DARL 52 and Solan Local (YSPUHF, Solan). Besides these, varieties selected by farmers over the years are also available in the market, e.g., Jamnagar Local, Ooty Local, Jeur Local etc. At present, there are 25 varieties in garlic (Table 5).

Table 5. Varieties of garlic and their important horticultural traits

Variety	Institution	Year of release	Photoperiod	Colour	Yield potential (t/ha)
G-41 (Agrifound White)	NHRDF	1989	Short Day	White	13
G1 (Yamuna Safed)	NHRDF	1991	Short Day	White	15-17
G-50	NHRDF	1996	Short Day	White	15-20
G282	NHRDF	1990	Short Day	White	17-20
G323	NHRDF	1990	Short Day	White	17-20
Godavari	MPKV	1987	Short Day	White	10-11
Shweta	MPKV		Short Day	White	10-11
T-56-4	PAU		Short Day	White	8-10
Bhima Omkar	DOGR	2009	Short Day	White	8-10
GG4	JAU	2009	Short Day	White	
Ooty1	TNAU		Intermediate	White	15-17
G313(Agrifound Parvati)	NHRDF	1992	Long Day	Purple	17-22
VLG1	VPKAS		Intermediate	White	14-15
DARL52	DARL	2003	Intermediate	White	12-15

Garlic breeding

Traditional garlic-breeding research has been limited to evaluation for yield and other morphological characters to identify the best genotypes (Figliuolo *et al*, 2001; Khar *et al*, 2005c, 2005e). Genetic studies have revealed positive interaction between plant-height, bulb-weight, bulb-diameter and mean clove-weight (Zhila, 1981). Significant positive correlation between clove and bulb mean-weight, negative correlation between clove mean-weight and clove-number has also been reported (Baghalian *et al*., 2005). Variation in yield is explained by leaf number and bulb mean-weight. Therefore, these important characteristics could help in garlic selection programme and yield improvement (Baghalian *et al*, 2006).



Bigger cloves > 1.5 g enhances yield

Although garlic is propagated vegetatively, considerable variation has been found in morphological traits (Shashidhar and Dharmatti, 2005; Khar *et al*, 2006). Major characters found to contribute to genetic diversity are bulb weight, diameter, yield, number of cloves per bulb, maturity, plant height, number of green leaves and bulbing period. Diversity assessment on the basis of morphological (Panthee *et al*, 2006; Baghalian *et al*, 2005), physical-chemical, productive and molecular characteristics (Mota *et al*, 2004), allicin content (Baghalian *et al.*, 2006), pungency (Natale *et al*, 2005), productive and qualitative characteristics (Resende *et al*, 2003) and chemotaxonomic classification (Storsberg *et al*, 2003) have been studied. In diversity assessment, Baghalian *et al*, (2005) did not detect any significant relationship between genetic diversity and geographical origin. Therefore, probably, genetic factors have more influence than ecology.

Allicin is a major chemical constituent of garlic and is use in pharmaceuticals. Multiple factors, viz., genotype, environment, S fertilization and light spectrum (Huchette *et al*, 2005), relative water content, soil type and harvesting date (Yang *et al*, 2005) have been found to influence allicin content in garlic bulbs, whereas, Baghalian (2005) found no significant correlation between ecological condition and allicin content.

Production of true seed in garlic (*Allium sativum* and *A. longicuspis*) has been known for several years. It was with the discovery of fertile clones by Etoh (1986) that efforts were started to induce flowering and seeds in garlic. With the advent of flowering garlic, Jenderek and Hannan (2004) were able to evaluate reproductive characteristics and true seed production in garlic germplasm and were successful at producing S1 bulbs in a few fertile clones. This represented valuable material for studies on garlic genetics (Jenderek 2004). Jenderek and Zewdie (2005) studied within and between family variability for important bulb and plant traits and observed that bulb weight, number of cloves, and clove weight were the main factors contributing to yield, and concluded that vegetative propagation of garlic over the centuries had produced highly heterozygous plants. Koul *et al* (1979) studied prospects for garlic improvement in the light of its genetic and breeding systems and Simon and Jenderek (2004) made a comprehensive review about flowering, seed production and genesis of garlic breeding.

Cultivated garlic, being non-flowering, has limited variability. Breeders depend upon natural clonal mutations and selection of superior clones from the germplasm. Induced mutations and somaclonal variation are the best way to broaden germplasm.

Biotechnological approaches

Micropropagation studies:

Different organogenic responses have been studied in several *in vitro* culture systems in onion. In general, two types of tissue have been used for induction of shoot cultures; inoculation of scale bases excised from the basal parts of bulbs or onion sets (Kahane *et al*, 1992) and immature flower buds (Mohammed Yaseen *et al*, 1995, Asha Devi and Khar, 2000). Callus has been induced on a wider range of explant tissues including bulb, set or seedling radicle (Dunstan and Short, 1978), shoot tip, seed and root tip (Khar *et al*, 2005a).

Micropropagation through regeneration of axillary buds from basal plates (Seabrook, 1993), development of somatic embryos from basal plate, roots derived from anther

(Suh and Park 1995), meristematic root tubercles (MRT's) (Tapia, 1991) has been reported. Callus formation and regeneration from different explants has been reported from root tips (Khar *et al*, 2005c), shoot tips (Khar *et al*, 2003), apical meristem with one leaf primordium (Lee *et al*, 1988), young leaves (Lu *et al*, 1982), protoplasts (Fellner and Havranek, 1994) and through embryogenesis *via*. culture of sprout-leaf (Wang *et al*, 1994). Ayabe and Sumi (1998) developed a novel tissue culture method, stem disc culture, wherein the restricted part of the under-developed stem of the garlic clove, called the "stem disc" was used for differentiation of twenty to thirty shoots consistently from a single clove within one month of culture.

Somaclonal variation

Reports on somaclonal variation among garlic regenerants are limited. Novak (1980) reported variation in a range of phenotypic characters including plant height, leaf number, bulb weight and shape and number of cloves within a bulb. Vidal *et al* (1993) found a somaclone possessing consistently higher bulb yield than its parental clone. Al-Zahim *et al* (1999) tried to detect somaclonal variation through RAPD and cytological analysis and concluded that no association existed between the rate of variation for molecular and cytological characters either by comparing cultivars or examining individual regenerants.

In garlic, it being a sterile plant and vegetatively propagated, genetic variation can be induces only by somaclonal variation, induced mutations or genetic transformation (Novak 1990; Kondo *et al*, 2000). Restoration of fertility and, therefore, of sexual reproduction would permit genetic studies and classical breeding. In addition, fast propagation of desired genotypes *via*. true seeds would be expected to result in reduction of storage costs and fewer injuries caused in the production field by viruses, diseases and pests transmitted by infected propagules. For induction of flowering, Tizio (1979) suggested that gibberelic acid with adenine or biotin could stimulate normal development of some flowers on pieces of garlic flower-stalk growth *in vitro*, while inhibiting formation of aerial bulbils on the inflorescence. However, no seeds were produced.

Genetic transformation

As monocotyledons, the *Allium* species were predisposed to be recalcitrant to transformation. It has, therefore, been relatively under-studied with respect to application of biotechnology. Successful transformation of one onion cultivar, mediated by *Agrobacterium tumefaciens* was reported by Eady *et al* (2000) using immature embryos as inoculated explants. Zheng *et al* (2001) developed a reproducible *Agrobacterium tumefaciens* mediated transformation system both for onion and shallot with young callus derived from mature embryos with two different *Agrobacterium* strains. In India, Khar *et al* (2005b) reported that in onion, callus proved to be the best explant source for genetic transformation, followed by shoot tip and root tips. Aswath *et al* (2006) devised a new selection system for onion transformation that does not require use of antibiotics or herbicides, using *Escherichia coli* gene that encodes phosphomannose isomerase (pmi). Through a single genetic transformation in onion. Eady *et al* (2008) were able to develop "Tear-free Onion" by suppressing the lachrymatory factor synthase gene, using RNA interference silencing.

Untill 1998, no report on garlic transformation was published. Barandiaran *et al* (1998) reported transfer of uidA gene into different garlic tissues, including regenerable calli, through biolistic particle delivery. Garlic tissues showed a high endogenous nuclease activity, preventing exogenous DNA expression. Since then, genetic transformation in garlic has been reported through indirect (Kondo *et al*, 2000) as well as direct (Sawahel, 2002) transformation system. Park *et al* (2002) were the first to generate transgenic plants resistant to chlorsulfuron, a sulfonylurea herbicide.

Haploid induction

Attempts to produce haploid plants *via*. androgenesis have failed (Keller and Korzun, 1996). Campion *et al* (1985) were successful only in getting anthers containing microspores with 1-3 nuclei after which the tapetum degenerated and the microspores died. First reports on successful haploid induction *via*. gynogenesis were given by Muren (1989) using unpollinated ovaries and were subsequently followed by other researchers. Several attempts to improve the haploid induction procedure using different culture conditions or altering media components were tested later. Variation in gynogenic response among long-day onion accessions was studied by Bohanec and Jakse (1993) and they reported that genotype of the donor plant had a crucial influence on haploid induction ability and that the less labour- intensive, single step flower induction procedure was an efficient method for obtaining high frequency homozygous embryo induction rate. Campion *et al* (1995) regenerated haploid plants *via* gynogenesis and also revealed their homozygosity based on morphological, isozymic and molecular studies.

Virus-free garlic

Garlic is affected by a viral mixture including mainly Potyvirus, Carlavirus and Allexivirus. This causes 78% bulb-weight reduction (Conci *et al*, 2005). Elimination of diseases, particularly viruses, is an important concern in production of planting material in garlic. Production of virus-free garlic plants has been attained through shoot tip culture (Pena-Iglesias and Ayuso, 1982), meristem tip culture (Li *et al*, 1995) and by thermotherapy in combination with meristem tip culture (Senula *et al*, 2000) and chemotherapy (Senula *et al*, 2000). Improved methods for multiple shoot formation and virus-free garlic stocks have been developed (Conci *et al*, 2005) leading to development of superior clones (Izquierdo and Gomez, 2005). For virus identification electron microsocopy, DAS- ELISA test (Fajardo *et al*, 2002) and RT-PCR techniques are being routinely used. RT-PCR tests have been developed for detection of onion yellow dwarf virus OYDV), garlic carla virus (GCLV) and mite-borne viruses (garlic mite-borne filamentous virus) (Bertaccini *et al*, 2004). Virus-free garlic stocks exhibit an increase in yield and other morphological traits (Fajardo *et al*, 2002). It has also been found that virus- free plants reinfected in 2-3 years of cultivation in the open field (Melo *et al*, 2006).

Molecular markers

Allium is a large genus of approximately 600 species and classification of such a large genus has proved difficult and many ambiguities still remain. Havey (1991) suggested that there could be a role for genetic markers in systematic studies of *Allium*. Bark *et al* (1994) studied introgression of *A. fistulosum* genes into *A. cepa* background using restriction fragment length polymorphism (RFLP) analysis. Van Heusden *et al* (2000) presented a genetic map based on amplified fragment length polymorphism (AFLP) in an interspecific cross of *A. roylei* and *A. cepa* and reported one of the allinase genes (a key enzyme in sulphur metabolism) and a Sequence Characterised Amplified Region (SCAR) marker linked to the disease resistance gene for downy mildew on the map. Gokce *et al* (2002) sequenced the genomic region corresponding to the cDNA revealing the closest RFLP to Male sterility (Ms) gene in their efforts on molecular tagging of the Ms locus in onion. Mapping studies in onion have thus far been scarce. King *et al* (1998) presented a low-density genetic map of restriction fragment length polymorphism (RFLP) based on an interspecific cross showing, that, genomic organization of onion was complex and involved duplicated loci. Reasons for delay in molecular marker studies in onion are: biennial nature of onion, it's severe inbreeding depression and its huge genome size. While RAPDs have been used successfully for genetic studies in *Allium*, the size of the genome may cause many problems, such as rather poor reproducibility and high backgrounds. Simple Sequence Repeats (SSRs), also called microsatellite markers, are codominantly inherited and reveal high levels of polymorphism. Fischer and Bachmann (2000) identified a set of informative STMS (Sequence Tagged Microsatellite Sites) markers for which can be used for distinguishing accessions and for studying interspecific taxonomic analysis using close relatives of *A. cepa*.

Garlic has been cultivated for millennia, but the taxonomic origins of this domestication process have not been identified. Modern taxonomy subdivides the world's garlic germplasm into five distinct groups: Sativum, Ophioscordon, Longicuspis, Subtropical and Pekinense (Fritsch and Friesen, 2002). The Longicuspis group from central Asia is recognized as the most primitive, the one from which the other group were derived (MaaB and Klaas, 1995; Etoh and Simon, 2002; Fritsch and Friesen 2002). Central Asia was hypothesized to be the primary centre of garlic evolution and diversity (Fritsch and Friesen 2002), and recent studies on primitive garlic types in the Tien-Shan mountains strongly support this assumption (Etoh, 1986; Kamenetsky *et al*, 2003).

A wide range of morphological diversity has been observed in garlic including flowering ability, leaf traits, bulb traits, plant maturity, bulbing response to temperature and photoperiod, cold hardiness, bulbil traits and flower traits (Simon and Jenderek, 2003). MaaB and Klaas (1995) included subtropical and Pekinense clones in their study, and suggested that the subtropical clones were clearly separated from all other types, while the Pekinense subgroup was relatively similar to the stalking type. RAPD techniques have been mostly reported for characterization of garlic germplasm from different researchers all over the world. RAPDs have been used for characterization of Australian (Bradley *et al*, 1996), Taiwanese (Hsu *et al*, 2006), Brazilian (Buso *et al*, 2008), Chinese (Xu *et al*, 2005), Chilean (Paredes *et al*, 2008), Guatemalan (Rosales *et al*, 2007) and Indian garlic (Khar *et al*, 2008). In addition to this, AFLP (Amplified Fragment Length Polymorphism) technique has also been used to characterize garlic (Ipek *et al*, 2003; Lampasona *et al*, 2003; Volk *et al*, 2004; Ipek *et al*, 2005). Ipek *et al* (2003) compared AFLPs, RAPD and isozymes for diversity assessment of garlic and detection of putative duplicates in germplasm collections and concluded that there was good correlation between the markers and demonstrated that genetic diversity among closely-related clones, which could not be differentiated with RAPD markers and isozymes, was detected by AFLPs. Therefore, AFLP is an additional tool for fingerprinting and detailed assessment of genetic relationships in garlic. Most of the reports have concluded that diversity assessment is not correlated with geographical location though a few studies reported correlation between geographical locations and the diversity (Lampasona, 2003). Volk *et al* (2004) reported that 64% of the U.S. National Plant Germplasm System's garlic collection, held at the Western Regional Plant Introduction Station in Pullman, Washington, USA, and 41% of commercial garlic collections, were duplicates. Rapid characterization of garlic accession is important for avoiding duplicate genotypes. For this purpose, Ipek *et al* (2008) developed several locus-specific polymerase chain reaction (PCR) based DNA markers and tested them for characterization of garlic clones and concluded that locus-specific markers could be used as another tool for rapid characterization of garlic germplasm collection. Markers have also been used to clarify the taxonomic status of other well-characterized locally grown garlics (Ipek *et al*, 2008; Figliuolo and Stefano, 2007). Geneic fidelity of micropropagated crops (Al Zahim *et al*, 1997, 1999), traits like pollen fertility (Etoh *et al*, 2001) and marker related to white rot (Nabulski *et al*, 2001) have also been reported.

A wide range of morphological diversity has been observed in garlic including flowering ability, leaf traits, bulb traits, plant maturity, bulbing response to temperature and photoperiod, cold hardiness, bulbil traits and flower traits (Simon and Jenderek, 2003). With the reporting of flowering garlic, linkage maps have been developed (Ipek *et al*, 2004; Zewdie *et al*, 2005) which will help tag important genes in future.

Production technology

There has been spectacular increase in area and production over the last 27 years in both crops but productivity remains almost static. There is a vast scope for increasing the productivity by enhancing genetic potential of varieties through resistance-breeding, innovations in agro-techniques, sustenance of productivity through better management of pests and diseases and improving post-harvest life.

Nursery management

In India, onion is mainly grown by transplanting. Onion seeds are sown on raised-beds in the nursery. The width of bed should be about 0.6 to 1 m and length may vary according to level of the soil (Pandey, 1989). According to Shinde and Sontakke (1986), 10-15 cm raised-beds of about 3-6m length and 1 m width are prepared. About 70 cm distance is kept between two beds for irrigation and intercultural operations. Seeds are sown in lines at a distance of 4-5 cm and seeds sown not beyond 2-3 cm depth in soil. To check post-emergence damping-off, drenching of the nursery with 0.1% Brassicol/copper oxychloride or 0.2% Captan should be done (Srivastava, 1978). In north India, nursery sowing of *kharif* onion from May to June is recommended. According to Sharma and Kumar (1982), higher yield was obtained when nursery was raised in late June or early July. Bhonde *et al* (1987) recommended 30th August transplanting for *kharif* onion production in Nasik area. Further, Singh and Singh (1974) found that 5-6 week old seedlings performed better than 4 or 7 week old seedlings.

Planting material selection in garlic

Garlic is propagated by cloves, which are carefully detached from composite bulbs without damage or injury to get higher sprouting in field. Usage of different sizes of garlic mother cloves as planting material varies in different regions of India and in other countries. Generally, cloves of medium to big size are recommended for production of bulbs for consumption, whereas smaller cloves for further propagation. An investigation was carried out in Nasik, Maharahstra during three successive *rabi* seasons and results revealed that largest clove size and widest spacing were significantly better than other clove sizes and spacings adopted (Lallan Singh *et al*, 1996). However, large clove size and planting in ridges or furrows produced the highest marketable bulb yield, as per Kotgirwar *et al* (1998). Bulb yield increased with increasing clove size. Bulb weight, DM and diameter were higher with larger cloves (Ramniwas *et al*, 1998). Similar results were also observed by Alam *et al* (2000). Bulb diameter and bulb weight per ten bulbs increased with increasing clove size. The highest bulb yield (20.92 t/ha) was also obtained with sowing the largest clove in garlic cv. LCC-1 at Punjab (Brar and Gill, 2000).

Studies conducted at DOGR revealed that among the various sizes of mother cloves evaluated for planting, mother clove size of 1.4-1.6 g recorded higher marketable bulb yield combined with minimum storage loss (Sankar and Lawande, 2009). Based on research work conducted in mother clove selection at various places suggested that requirement of seed bulbs differs from variety to variety and depends on bulb size, bulb weight, number of cloves and weight of cloves. Average mother clove size for planting should be more than 1.0 g and seed rate should be 500 – 950 kg/ha., depending upon planting material availability.

Water management

Onion and garlic are very shallow-rooted bulb vegetable corps and are very sensitive to moisture stress conditions particularly during bulb initiation and development. Frequent irrigation is, therefore, necessary for better bulb development. Excess moisture or waterlogged condition during these stages leads to development of diseases like basal rot and purple blotch. Similarly, continuous irrigation towards maturity leads to secondary rooting which, in turn, develops new sprouts and such bulbs do not keep longer in storage. Withholding irrigation for two-three weeks prior to harvest in onion is very essential. However, for garlic, some amount of light moisture is necessary at harvest for easy uprooting of bulbs.

The most common method of irrigation is basin or border-strip flooding or furrow irrigation. Root system is normally restricted to top 3 cm in both the crops and roots seldom penetrate deeper than 15 cm. Water requirement depends mostly on soil type, evaporation, and crop stage. Considerable research work on method and scheduling of irrigation water has been done to net higher bulb yield.

According to Saha *et al* (1997), optimum exploitation of yield potential of Taherpuri onion, with maximum efficiency of irrigation-water use and 10 to 20% depletion of field-capacity moisture are the most suitable criteria for irrigation. Ramamoorthy *et al* (2000) reported onion cv. CO4 to be irrigated at IW/CPE values of 0.6, 0.8, 1.0 or 1.2 during *kharif* and summer seasons. Bulb yield increased as IW/CPE value increased. Water use efficiency was greatest when onion was irrigated at IW/CPE of 1.2. Nam *et al* (2007) observed that the distribution rate of large size of garlic bulbs (above 45 mm diameter) ranged as 58.9-76.5% under irrigation, but 39.4% under water-stressed condition. Yield of garlic decreased significantly under no-irrigation. Irrigation at 3-day intervals significantly affected number of leaves per plant, plant height at maturity, bulb yield, bulb weight, number of cloves per bulb and clove weight, while, increase in number of days between irrigation intervals negatively affected growth and yield (Ahmed *et al*, 2007).

Micro-irrigation

Studies at MPKV, Rahuri revealed that highest bulb was obtained with drip irrigation at 100% CPE. Water-expense efficiency was higher with all rates of drip irrigation than with surface irrigation (Patel *et al*, 1996). Studies on the efficacy of the micro-sprinkler irrigation revealed increased yield of garlic with decrease in micro-sprinkler spacing by 38% (Pawar *et al*, 1998). The micro-sprinkler irrigation method was suitable for irrigating a close-growing crop like garlic by closely spacing the micro-sprinklers. Among the irrigation methods evaluated, drip irrigation at 100% PE recorded the highest marketable bulb yield in both the crops with 30-40% water saving in comparison with surface irrigation (Sankar *et al*, 2008, 2009).

Micro irrigation in onion and garlic

Fertigation

Drip irrigation with the recommended rate of solid fertilizer in 2 applications gave the highest bulb yield (496.35 q/ha) while drip fertigation at 50% of the recommended rate gave the highest bulb quality in onion (Chopade *et al*, 1998). Optimum yield and acceptable bulb quality of onion was obtained from drip irrigation, combined with fertigation using NPK liquid fertilizer @150:125:200 kg/ha Balasubramanyam *et al*, 2000. In the case of garlic, higher yield response was obtained by fertigation than by soil-application of N. Split application of N at 120 kg/ha produced higher yields. Overall results indicated that with N fertigation improved bulb yield, NUE, and WUE (Mohammad and Zuraiqi, 2003). Higher yields of garlic were obtained by P application at 80 kg/ha through drip-fertigation. According to Rumpel and Dysko (2003), higher marketable yields were produced when 50 kg N/ha was applied through fertigation

Fertigation in onion and garlic

(41% increase). Application of water-soluble fertilizers @ NPK 100:50:80 kg /ha as basal +50 kg N in onion and NPK 50:50:80 + 50 kg N in seven splits in garlic through drip-irrigation was the best treatment in terms of yield and cost: benefit ratio (Sankar *et al*, 2005b).

Integrated Nutrient Management (INM)

Nutrient management in onion and garlic production is mainly by application of inorganic fertilizers. Proper application of organic manures, crop residues, green manure, suitable crop rotation, balanced application of fertilizers based on soil-testing important. This can be achieved through integrated nutrient management practices.

According to Goto and Kimoto (1992), the highest commercial yields of onion bulbs were obtained by application of castor-bean cake along with P and K and, FYM combined with NPK. Warade *et al* (1996) obtained the highest bulb yield (22.7 t/ha) with 40 tonnes of FYM and biofertilizer inoculation along with NPK, thereby saving 25% on nitrogen alone. Bhonde *et al* (1997) revealed that treatment of FYM @ 15 t/ha + *Azotobactor* seedling dip and Nimbicidin application indicated a possibility of replacement of inorganic fertilizers under organic farming. Thilakavathy and Ramaswamy (1998) also opined that 2 kg/ha of *Azospirillum* and Phosphobacteria with 45 kg N and 45 kg P was more remunerative compared to 60:30:30 kg of NPK/ha.

Reddy and Reddy (2005) found that among various treatment combinations, vermicompost at 30 t/ha + 200 kg N/ha recorded the highest plant height and number of leaves per plant in onion, but was at par with vermicompost at 30 t/ ha + 150 kg N/ha in terms of bulb length, bulb weight in an onion-radish cropping system. Studies conducted at DOGR recommended a dose of 150kg N + 50kg P + 80kg K + 45kg Sulphur/ha. for *rabi* onion and 100kg N + 50kg P + 50kg K + 45 kg Sulphur/ha for garlic along with integration of 10 tons of FYM + 10 tons of poultry manure and use of *Azotobacter* @ 4kg/ha. The results revealed vermin compost treatment to increase scorodose accumulation in garlic bulbs and was directly related to harvest index, resulting in greater yield and bulb quality (Arguello *et al*, 2006).

Micronutrient application

Gupta and Ganeshe (2000) revealed that zinc sulfate (25kg/ha) + borax (10kg/ha) promoted yield marginally by 45.8kg/ha in garlic over the control (recommended dose of N, P and K). Application of boron at 0.1% + sodium molybdate at 0.05% (w/v) recorded the highest healthy bulb yield and reduced premature field-sprouting of cloves (Selvaraj *et al*, 2002). Foliar application of urea + zinc + copper resulted in lowest decay and total loss in stored onions (Singh *et al*, 2002). Improved plant growth and yield characters were observed at 0.03% boron and zinc at 0.025% (Sharangi *et al*, 2003). Abd-El-Moneem *et al* (2005), observed reduction in basal rot infection in garlic when cloves were treated with Zn and Cu before planting. Srivastava *et al* (2005) reported that boric acid at 0.1% and zinc sulfate at 0.4% resulted in maximum bulb yield and total soluble solids. Nitrate reductase (NR), catalase (CAT), peroxidase (POD) and superoxide dismutase (SOD) activities, soluble protein content, photosynthetic pigment content, sugar, protein content and some other photosynthetic parameters in garlic leaves were highest in a treatment with 0.3 g/pot of zinc (Yang *et al*, 2005).

Organic production of onion and garlic

Although organic vegetable production provides better quality food and a balanced environment, almost 25-40% lesser yield was recorded in organic farming system in both the crops in initial years. However, bulb yield increased consistently in succeeding years in the same field. Organic production experiment conducted at DOGR revealed that with soybean as the preceding crop in *kharif* season, followed by onion or garlic in *rabi* season with application of either poultry manure (alone or in combination with FYM) along with biofertilizers (combined with foliar application of organic growth stimulants and organic plant protection measures) gave comparatively better yield and good storage-life in both the crops. According to Sankar *et al* (2009), higher marketable bulb yield in white onion along with better post-harvest storage-life was obtained with combined application of FYM (FYM 50% as equivalent to recommended dose of NPK) + poultry manure (50% as equivalent to recommended dose of NPK) + biofertilzers + foliar application 3% Panchakavya .

WEED MANAGEMENT

Crop-weed competition and extent of losses

Monocotyledonous weed population was found to increase upto 60 DAT and decreased in subsequent stages. Dicotyledonous weed numbers were found to increase with advancement in crop age (Singh and Singh, 1990).

The critical period of crop-weed competition in onion occurred from 15 to 45 days after transplanting (Shuaib, 2001), 21-28 days in the first season and 42-49 days in the second season, depending on the competing weed species and their densities in garlic and reduction of bulb yield was upto 85% (Qasem, 1996). DOGR experiment results revealed that yield losses in onion and garlic were to the tune of 12 – 94.8% depending upon types of weed flora, their intensity and duration of crop – weed competition.

Chemical weed control in onion and garlic

In onion and garlic, very close spacing and a shallow root system make mechanical method of weed control difficult and, sometimes, damage developing bulbs.

In garlic, application of 0.9kg Fluchloralin/ha pre-planting + 1.25kg Nitrofen/ha 15 days after transplanting was most effective in decreasing weed population and resulted in bulb yield of 3.76t/ha compared with 3.85t with 2 hand-weedings (Patel *et al*, 1985). According Abdel and Haroun (1990), Goal (Oxyfluorfen 23.6%) at 0.75 litres/ha applied 3 weeks after transplanting or Stomp Pendimethalin 50% at 2.0 litres applied after transplanting and before irrigation gave the best control, resulting in highest bulb yield. Tamil Selvan *et al* (1990) reported that post-sowing application (3 days after sowing) of Oxyfluorfen at 0.1-0.6kg/ha gave more effective control of weeds in onion.

Integrated weed management practices

Vinay Singh (1997) suggested that mulching at 30 DAT gave maximum bulb yield (26.33t/ha), followed by 3 hand-weedings at 30, 60 and 90 DAT. Pendimethalin at 1.0 kg a.i./ha + 1 manual weeding at 60 DAT proved to be the most economical with a cost:benefit ratio of 2:3.1. Well prepared and pre-irrigated seedbed plots covered with 50 μm-thick, transparent, polyethylene mulch for 6 weeks prior to onion planting gave the lowest number and weight of weeds/m^2 and higher seedling emergence (Abdallah ,1998).

In the case of garlic, weed competition for only 14 days from crop emergence was sufficient to reduce yield, while, weed-free periods of 35 or 28 days from crop emergence failed to produce bulb-yields higher than weed-infested plots. The minimum weed-free period required to produce a bulb size was 21- 49 days from crop emergence. Sharma *et al* (1983) reported that the most effective treatments were 1kg Oxadiazon/ha post-emergence, followed by 0.95kg Fluchloralin/ha pre-planting, which controlled both monocot and dicot annual weeds and gave higher net returns than weed-free control in garlic. Application of Oxadiazon at 1.5 kg/ha and Pendimethalin at 1.0kg/ha + HW at 65 DAP was most effective with high yield, net return, and cost:benefit ratio at Sirmour, Himachal Pradesh (Ankur *et al*, 2002; Singh *et al*, 2002).

Cropping systems

In recent years, soil fertility - fertilizer use research is focused on cropping sequence. Due to increased fertilizer prices and consideration for ecological sustainability, interest is focused on intensive cropping system, especially legume crops, in a sustainable crop sequence as an alternative or supplement to chemical fertilizers. Both onion and garlic are short-duration and shallow-rooted crops and are suitable for various cropping patterns including intercropping and sequential cropping, depending upon location, nature of soil and climatic conditions.

Arya and Bakshi (1999) observed that onion cultivation was more profitable when okra and radish, as one of the component vegetables, are grown in the vegetable sequence. Studies conducted at DOGR revealed that in *kharif* season followed by onion or garlic in *rabi* are ideal cropping sequences under western Maharshtra conditions in terms of yield, soil health and cost benefit ratio (Sankar *et al*, 2005 and 2006). The highest intercrop yield was obtained when sugarbeet was sown in ridges, 60cm apart, and with 25cm between sugarbeet and onion. A gradual decrease in onion and garlic yield was observed with increasing inter- and intra-spacing. The highest land equivalent ratio (LER) was obtained from sugarbeet-onion intercropping which was higher than sugar beet-garlic intercropping.

INSECT PEST MANAGEMENT

A significant portion of onion and garlic yield is lost due to a major pest, onion thrips, *Thrips tabaci*. It remains the major pest species worldwide while other species like *Frankliniella occidentalis* and *F. fusca* though recorded in some areas, but never reached damaging levels. Some of the principal alternate hosts include cabbage, cotton, tomato, cucumber, melons, pumpkins, strawberries and many flowering plants. According to Larentzaki *et al* (2007) volunteer onion plants, weeds such as *Amaranthus hybridis* and *Chenopodium album* and soil within and around onion fields, are the potential overwintering sites of the adult pest.

In Maharashtra, yield losses were estimated at 50% in *rabi* season if control measures were not taken (Srinivas and Lawande, 2004). In addition to direct damage, thrips attack aggravates the fungal pathogen *Alternaria porri*, that causes purple blotch through mechanical transmission (Bhangale and Joi, 1983). Similarly, severity of *Stemphylium* blight also increases in the presence of large numbers of thrips. *Thrips tabaci* also acts as a vector of the Iris Yellow

Spot Virus which has a detrimental effect on bulb and seed yield (Gent *et al*, 2004 and Hoepting *et al*, 2007).

Management of thrips

Monitoring

Monitoring of thrips can be helpful in initiating appropriate control measures at the right time because of their small size, cryptic behaviour, egg-deposition inside the plant tissue and propensity to hide themselves in tight spaces. Thrips generally migrate to a new field from the old plantings. However, no distinct immigration trends were noticed (Gangloff, 1999). Sticky traps are commonly used for detecting thrips populations. Various colours were found attracting different species of thrips in various geographical areas (Cho *et al*, 1995; Diraviam and Uthamasamy, 1992; Fernandez and Lucena, 1990). Yellow and bright blue traps are widely used.

Population dynamics and forecasting

Positive (Hamdy and Salem, 1994) or negative (Warriach *et al*, 1994) or no (El-Gendi, 1998) correlations were obtained between maximum temperature and thrips populations. Relative humidity and rainfall had a negative effect on thrips population. Heavy rains wash thrips off the plants down to the soil, causing a sudden decline in their population. Thrips are especially problematic during hot, dry years because more number of generations are produced and the enjoy decreased mortality due to lack of rainfall (Shelton, 2003). According to a study, two population peaks – one in the month of August, and the other in January-February, occur in western Maharashtra (Srinivas and Lawande, 2004). During this period, hot and dry climate prevails and thrips multiply faster to reach harmful proportions.

Cultural methods

Good crop-management practices such as removing alternate weed hosts on bunds, and destruction of culls of onion and garlic, avoiding successive plantings of onion and garlic or other preferred hosts, are all helpful in reducing thrips population. Because of their swift movement and mobility, practices like crop-rotation or isolation from the immigration source have little effect on thrips infestation. Thrips are carried by wind. Therefore, planting in upwind direction could be helpful in escaping infestation from old plantings to some extent, in the initial stages.

Planting date: By making adjustments in transplanting dates, onions can be made tolerant to early thrips-attack and satisfactory yields can be obtained with minimum chemical intervention. In Maharashtra, onions are grown in all three seasons, viz., *kharif*, late *kharif* and *rabi*. Onion crop planted in the months of September and October (late *kharif)* had less severe attack by thrips and required little crop protection, compared to *rabi* crop planted in November-December. Yield loss of 50% was observed in 15^{th} November planted crop (Srinivas and Lawande, 2004).

Mulching : Thrips are colour-sensitive and coloured mulches may be employed for their control. Reflective mulch with aluminum paint (Scott *et al*, 1989) repelled 33-68% of the thrips and was found to be more effective, particularly, at the seedling stage rather than at plant maturity (Lu, 1990). However, reflective mulches were not promising in New Zealand (Toor *et al*, 2004).

Irrigation : Thrips damage may get magnified if the crop is under water stress. Adequate irrigation throughout the growing season is critical in minimizing damage (Fournier *et al*, 1995). The stages of thrips in the soil were strongly affected by water content of the soil (Bieri *et al*, 1989). Field trials at DOGR suggested that sprinkler irrigation reduced thrips population considerably, compared to drip and surface-irrigation. In garlic, sprinklers were not that effective, mainly due to the closer-inner leaf alignment that protects thrips from splashes of water.

Fertilization : The role of plant nutrition on onion thrips infestation is not clear. Thrips infestation did not vary when the crop was supplied with organic manure or mineral nutrition (Goncalves, 2004). Higher doses of nitrogen make the plant succulent and make it vulnerable to sucking-pests.

Barriers : Thrips are weak fliers and can be carried by wind. Therefore, planting live-barriers like maize can effectively block adult thrips from reaching onion plants. Two rows of maize or an inner row of wheat and outer row of maize surrounding onion plots (250sq.m) blocks adult thrips upto 80% (Srinivas and Lawande, 2006). This practice brings down insecticide application by half. Highest benefit:cost ratio can be obtained with maize + wheat barrier around onion and garlic.

Biological control

Predators were found to be effective in reducing thrips population from 20-70% in greenhouses and polytunnels upon release; however, in open fields, their incidence is very low. A parasitoid *Ceranisus* sp was recorded in India but the incidence of parasitoid was low in the field as well.

At DOGR, the minute pirate bug, *Orius* sp., was found to be effective on thrips in garlic. Natural occurrence of this predator on garlic was observed, though not regularly. Crops like sunflower and maize attracted the predator, which later migrated to garlic (but only at the later stages of the crop). *Orius* spp. was widely reported against different thrips in protected cultivation of vegetables and flowers (Tommasini *et al*, 1997). General predators like green lacewing did not prefer onion and garlic, mainly due to pungency and leaf volatiles. Recently, another anthocorid bug, *Blaptostethus* sp., has been identified as a potential predator of onion thrips. However the predator lacks field-establishment and fast multiplication on the garlic crop.

Spray formulations of *Beauveria bassiana* were recommended for control of thrips. But, their efficacy was best under laboratory and greenhouse conditions only. Under laboratory and greenhouse conditions, besides *B. bassiana*, *Metarrhizium anisopliae, Paecilomyces fumosoroseus* and *Verticillium lecani* effectively killed *T. tabaci* and *Frankliniella* sp., (Kubota, 1999). Mortality of thrips was highest with *B. bassiana* at 26^{0}C and 75% RH (Murphy *et al*, 1998). Such high humidity seldom occurs under field conditions for long periods.

Plant resistance

In India, screening for resistance against thrips was started long ago in Maharashtra, Punjab, Gujarat and other parts of the country. Although the commercial varieties N-2-4-1 and Pusa Ratnar were found resistant to *T. tabaci* in Punjab (Darshan Singh *et al*, 1986; Brar *et al*, 1993), the former was susceptible to thrips in Maharashtra. The variety B-780 is moderately resistant to thrips. In Bihar, Pusa Red and N-53 had lowest thrips population during winter and monsoon, respectively. Many germplasm lines were identified as being resistant to thrips elsewhere in India. However, till today, no promising or consistent variety of onion is available in India for thrips resistance.

Some wild species like *A. galanthum* and *A. ampeloprasam* and some genotypes of *A. fistulosum* were found highly resistant to thrips (Srinivas *et al*, 2007b). However, breeding-hurdles with these species need to be worked out before going in for resistance breeding programme.

Botanicals and mineral oils

Neem, Karanj and Annona were less effective in controlling thrips than were insecticides (Gupta and Sharma, 1998; Altaf Hussain *et al*, 1999; Srinivas and Lawande, 2000a). Recent trials at DOGR suggested that mineral oil sprays @ 2% could bring down thrips population by 48%.

Chemical control

Effective management of thrips on onion relies primarily on foliar sprays of insecticides. Insecticide load on the crop can be brought down considerably by following economic thresholds and use of the insecticide at critical stages of growth. Economic threshold for onion was 30 thrips per plant during *rabi* season (Srinivas and Lawande, 2000b). Thrips control is critical during bulb initiation that begins in the seventh week after planting, through bulb formation. Highest benefit:cost ratio was obtained when thrips control was undertaken in 45-75 days old crop (Srinivas and Lawande, 2008).

Sometimes, late-planted crop suffers poor establishment when thrips incidence is higher. Seedlings, seedling-root dip with Carbosulfan (0.025%) or Imidacloprid (0.04%) for 2h before planting protects young plants upto 30 days (Srinivas and Lawande, 2007a).

It is commonly observed that re-infestation occurs soon, even after a good kill of thrips with insecticide sprays. Studies at DOGR showed that eggs lay in leaves and external immigration of thrips was the main source of re-infestation. Among different insecticides evaluated, occurrence of re-infestation was very low with Fipronil and Profenofos.

In India, insecticides like Dimethoate, Cypermethrin, etc., were recommended for thrips control. Among the relatively new insecticides, Carbosulfan, Methomyl, Lambda cyhalothrin, Profenofos, Spinosad and Fipronil were found effective in suppressing thrips population. A non-chemical, kaolin particle-film was evaluated against onion thrips. This reduced oviposition and increased mortality rate under laboratory conditions. Due to the importance of continuous coverage of plant material with film, better application methods need to be developed. Frequent application may also be required to cover newly-expanding foliage (Larentzaki *et al*, 2008).

DISEASE MANAGEMENT

Seed-borne diseases

Infestation by seed-borne fungi during storage is one of the major factors for quick loss of seed viability. Upmanyu and Sharma (2007) reported that purple blotch disease at above 60% severity caused significant reduction in seed-yield and quality. At 100% disease severity, 14%

loss in yield was observed. About 24 species of fungi have been identified in onion seeds produced under different climatic regions. Though all these species are found associated with onion seed and many are proven crop pathogens, only a few have been experimentally proved to be truly seed-borne (Maude, 1989). Generally, some pathogenic fungi detected in seed just after harvest but, in the course of storage, get eliminated and predominated by storage fungi like *Aspergillus niger*. Only *A. niger* and *Fusarium spp.* were transmitted from the seed to seedlings and sets (Koycu and Ozer, 1997).

Soil-borne diseases

There are several important soil-borne fungal pathogens that infect *Alliums* and produce common symptoms. Early attack can result in failure of emergence or collapse of seedlings, aggravated by drought. The major root-infecting fungal diseases of onion and garlic are: white rot (*Sclerotium cepivorum*), pink root (*Phoma (Pyrenchaeta) terrestris*), basal rot (*Fusarium oxysporum f. sp. cepae*, *F. oxysposum f. sp. allii*), southern blight (*Sclerotium rolfsii*), onion smut (*Urocystis cepulae*) and damping-off (*Pythium spp., Fusarium spp., Rhizoctonia solani*). Gupta *et al* (1983) reported 75-80% loss in onion nursery due to damping-off in warm and humid areas. Common fungi reported to be responsible for damping-off of seedlings are species of *Pythium, Phytophthora, Fusarium* and *Rhizoctonia*. Singh (2007b) reported that *Curvularia sp.* was also associated with onion damping-off. *Fusarium* caused delayed seedling emergence and seedling damping-off in addition to root and basal rot (Srivastava and Quadri, 1984).

Fusarium basal rot of onion and garlic occurs worldwide and is a common problem in onion seed crop. In India, pre-harvest spray of Carbendazim (0.1%) resulted in least decay of stored onion after 5 months from storage (Srivastava *et al*, 1996). Crop rotation of 4-5 years with non-host crop has been found effective in eliminating the disease. Mixed cropping with tobacco and sorghum is also effective in reducing disease severity (Srivastava and Pandey, 1995). Green-manuring increases antagonistic microbial population in the soil. Good drainage, deep ploughing in hot summer and avoiding injury during cultural practices reduces disease incidence. Girija *et al* (1998) found three lines viz., IIHR 141, IIHR 506 and Selection 13-1-1 to be consistently resistant to *Fusarium oxysporum* in the field under different growing seasons. Fungal antagonists, *Trichoderma viride, T. harzianum, T. hamatum, T. koningii*, *T. pseudokoningii*, and bacterial antagonists, *Pseudomonas fluorescens* and *Bacillus subtilis* were effective against *F. oxysporum* under *in vitro* conditions (Rajendran and Ranganathan, 1996).

Smut (*Urocystis cepulae*) is found in almost all onion-growing states. Chemical seed- treatment with Thiram or Captan (0.3%) checks soil-borne infection. Soil application of these fungicides in the nursery reduces seedling infection. Though pink root rot is not reported from India so far, a similar disease induced by *Fusarium solani* has been reported from Rajasthan by Mathur *et al*, (2007). Since pink root caused by *Phoma terrestris* often occurs in association with *Fusarium* basal rot, chances for confusion are therefore always associated with this disease, which needs due care and a thorough investigation. Root rot of onion is caused by *Rhizoctonia solani* and *Sclerotinia sclerotiorum* (Singh and Singh, 1984). *Rhizoctonia solani* has also been found to be associated with black scurf of white onion (Singh, 2008a).

FOLIAR FUNGAL DISEASES

Major foliar diseases of onion and garlic in India are purple blotch (*Alternaria porri*), *Stemphylium* blight, *Stemphylium vericariuno*, anthracnose or Twister disease, downy mildew and black mold. All these diseases can defoliate the crop prematurely.

Purple blotch

The fungus is seed-borne but its role in initiating disease outbreaks in hot climates is not well studied. The pathogen survives in crop debris as dormant mycelium and can remain viable for 12 months (Gupta and Pathak, 1988); but, this is reduced to less than 2 months if the debris is buried (Pandotra, 1965). Temperature, relative humidity and host-nutrition play an important role in infection (Khare and Nema, 1982). Spore-germination on leaves decreased with increase in nitrogen dose to the host, while, the reverse was true for potassium. Seed-treatment with Thiram (0.25%), crop rotation and summer ploughing are recommended for control of the disease (Gupta and Pathak, 1987).

Sources of resistance have been reported by many workers (Pathak *et al*, 1986; Dhiman *et al*, 1986). Onion varieties, Agrifound Light Red (Sharma, 1997), 53-3 (Pandotra, 1965), Agrifound Dark Red, Red Globe (Sugha *et al*, 1992), VL Piyaz 3 (Mani *et al*, 1999) and RO 59 (Mathur *et al*, 2006) were reported to be moderately resistant. Application of Mancozeb (0.25%) and Captafol

@ 0.2% (Gupta, *et al*, 1986a) Iprodione @ 0.25% (Gupta *et al*, 1996), Metalaxyl and Dinocap (Upadhyay and Tripathi, 1995; Srivastava *et al*, 1996) were found effective in controlling the disease.

***Stemphylium* leaf blight**

The disease is found in onion in all parts of the country but causes severe losses in northern India (Gupta and Pandey, 1986a). It has been reported in garlic too (Sinha *et al*, 1995; 1998). About 90% loss in seed yield was recorded. The disease is more severe in *rabi* than in *kharif* season. Another species of the same fungus, *S. botryosum*, causes black stalk- rot (Singh and Sharma, 1977a). It is presumed that the fungus survive on alternate hosts in the absence of onion crop. It infects plants after long, warm periods when leaves remain wet. Cultural control methods include long rotations with non-host crops, good field-drainage and reduced plant density to contain the diseases. Since the pathogen survives on dead plant tissues, sanitation of the field and collecting and burning the crop refuse reduces disease incidence. Barnwal and Prasad (2005) observed lowest disease intensity in a crop sown in the last week of November as compared to that sown in October. Irrigation at 10 day intervals and high doses of nitrogen resulted in reduced disease incidence (Srivastav *et al*, 2005).

A large number of fungicides have been tested by many workers but 3 to 4 sprays of 0.25% Mancozeb offer best control, with higher benefit:cost ratio (Gupta *et al*, 1996b). For onion seed crop, fortnightly sprays of 0.25% Mancozeb or 0.25% Iprodione are recommended (Srivastava *et al*, 1995). Rahman *et al* (2000) reported that leaf blight diseases caused by *Alternaria porri*, *Colletotrichum* sp., *Stemphylium* sp. and *Cercospora* sp., singly or combined, could be controlled by four sprays of Mancozeb @ 0.3%, starting from 45 days after transplanting. Among the newer fungicides, two sprays of Hexaconazole (0.1%) were found most cost-effective (Barnwal *et al*, 2006). Foliar spraying of leaf extracts (20%) of *Azadirachta indica* and *Datura metel* was also quite effective while, *Pseudomonas fluorescens* was comparatively less effective (Barnwal *et al*, 2003).

***Colletotrichum* blight / Anthracnose / Twister disease**

Characteristic field- symptoms are curling, twisting, chlorosis of leaves and abnormal elongation of the neck (false stem). Bulbs are smaller in size; some may rot before harvest while others rot in store. Ebenebe (1980) conclusively proved that the onion twister disease and onion anthracnose are caused by *Colletotrichum gloeosporioides* whose perfect stage is *Glomerella cingulata*. Since the pathogen survives on crop refuse, sanitation and destruction of infected plant-debris helps reduce the disease. Application of Benomyl @ 0.2% as soil-treatment is recommended (Remiro and Kirmati, 1975). Spraying Mancozeb @ 0.25% also gives good control. Cultivars IPA 3, Belem, IPA 9, Franciscana IPA 10, Vale Ouro IPA II and Roxinha de Belem were found resistant (Assuncao *et al*, 1999).

Downy mildew

Downy mildew (*Peronospora destructor*) is a serious problem in all parts of the world where onions are grown in cool and humid conditions. Bulbs used for seed production should be selected from healthy fields for management of the disease. Crop rotation for 3-4 years with non-host crop should be practised. Late planting, poor drainage, higher dose of fertilizer and frequent irrigation should be avoided, as these practices encourage high disease-incidence (Ahmad and Karimullah, 1998). Spraying Mancozeb@ 0.25% and Ziram @ 0.1% at 10-12 day intervals is recommended (Marikhur *et al*, 1977). Bulb and seedling-dip in Ridomil MZ @ 0.25% for 12 hrs followed by 2 foliar sprays gave effective disease control. *Allium roylei* posses resistance to downy mildew (Kofoet and Zinkernagel, 1990). Metalaxyl and Cyomaxanil proved most effective in reducing disease severity upto 88% (Palti, 1989). The low degree of fertility exhibited by hybrids between *A. cepa* and other *Allium* species restricts successful introgression of disease resistance. Onion lines IC-48045, IC-32149, IC-49371 and DOP-2 have been reported to be resistant to downy mildew (Sharma, 1997).

BACTERIAL DISEASES

Bacterial decay of onion is widely distributed in warm climates and causes severe problems. Seedling blight is caused by *Pseudomonas siccata* (Moniz and Patel, 1958). Moniz and Bhide (1964) reported infection by *P. gladioli pv. alliicola* in field crops as causing seedling blight of onion, resulting in streaking of leaves and premature death. The same pathogen is also known to cause stalk rot (Swarup *et al*, 1973) and bulb rot (Kumar *et al*, 2001). Brown rot is caused by *P. aeruginosa* (Gupta *et al*, 1986), while soft rot is induced by many bacteria, i.e., *Pectobacterium carotovorum* (Patel, 1972), *Pseudomonas marginalis pv. marginalis* (Raju and Raj, 1980a) and *Erwinia carotovora pv. carotovora* (Raju and Raj 1980b).

In the recent past, not much work has been done on bacterial diseases of *Alliums* in the country.

The best way to control bacterial diseases of onion is to grow the crop under best- possible condition of tilth, fertilization, drainage, crop rotation and freedom from weeds. It is necessary to dry the crop quickly after harvest. During rainy season, artificial curing is required. Resistant varieties are not known. It appears that at present, all onion cultivars are susceptible to bacterial infection and bulb decay.

VIRAL AND MYCOPLASMAL DISEASES

In India, onion yellow dwarf virus was reported by Dhingra and Nariane (1963) and Gupta and Pandey (1986b). It also affects garlic and leek. It is transmitted by aphids or mechanically, to onion. This disease is a common problem in seed production. Due to variability in N-terminal region of the viral coat protein in different isolates, ELISA may not be a preferred method for detection. As an alternative, a rapid and reliable detection protocol of RT-PCR was standardized by Arya *et al* (2006).

Irish Yellow Spot Virus is a relatively new disease of onion. It has recently become widespread in western counties, especially in the US. In India, it was first reported from Jalna and Nashik region of Maharashtra by Ravi *et al* (2006). Now, it has been reported from some other onion-growing states of the country.

Garlic is more vulnerable to viral infection. Some of these viruses are members are of the potyvirus group - Garlic Mosaic Virus (Ahlawat, 1974; Sastry, 1980), onion yellow dwarf virus and others are Carla virus - Garlic Latent Virus (Majumdar *et al*, 2007), Shallot Latent Virus and Carnation Latent Virus.

STORAGE DISEASES

Black mold (*Aspergillus niger*) is the most important post harvest disease under hot climates. In India, it is very common wherever onion or garlic is stored (Gupta and Srivastava, 1992). *Aspergillus niger* invades onion bulbs preferably through injured portion of the outer scales and colonizes bulbs, roots, neck, flowers, peduncle and leaves of onion plants in the field in that order of preponderance (Rajasab and Rao,1992). Pre-harvest spray (0.2%) of Carbendazim (12%) + Mancozeb (63%) and Iprodion, 20 days before harvesting, proved effective (Ahir and Maharishi, 2008). Onion smudge is the next important disease and had not been recorded in onion bulbs until the report of Singh (2007c).

The pathogenic fungus *Embellisia alli* is known to cause garlic bulb canker in many countries. Until interception of *E. allii* in garlic bulbs imported from China by the Indian Plant Quarantine Authorities, it was not known to occur in India (Latha *et al*, 2007). But in the same year, it was isolated from garlic bulbs collected from Himachal Pradesh. It was the first report of *E. allii* from the Indian soil (Singh and Khar, 2007). Storage diseases can be controlled by avoiding mechanical injuries during harvesting, by proper curing, storage under ideal conditions and sprays with Bavistin (Gargi and Roy, 1988). Garlic stored for table purposes may be fumigated with Formalin (Rath and Mohanty, 1986).

REFERENCES

Abd El Moneem, K.M.H., Fawaz, S.B.M., Saeed, F.A. and El Shehaby, A.I. 2005. Effect of clove size and certain micronutrients on *Fusarium* & basal rot of garlic. *Assiut J. Agril. Sciences*, **36**:163-175

Abdallah, 1998. Improving vegetable transplants using soil solarization. II. Onion (*Allium cepa*). *Ann. of Agril Sci.*, Special Issue, Volume **3**:831-843

Abdel A.S.M and Haroun, M.S.1990. Efficiency of some herbicides on weed control and yield of onion (*Allium cepa* L.). *Egyptian J. Agron.*, **15**:35-44

Aghora, T.S. and Pathak, C.S. 1991. Heterosis and combining ability in a line x tester cross of onion (*Allium cepa* L.). *Veg. Sci.*, **18**:53-58

Ahir, R.P. and Maharishi R.P. 2008. Effect of preharvest application of fungicides and biocontrol agent on black mold (*Aspergillus niger*) of onion in storage. *Ind. Phytopath.*, **61**:130–131

Ahlawat, Y.S. 1974. A mosaic disease of garlic in Darjeeling Hills. *Sci. and Cul.*, **40**:466-467

Ahmad Shabeer and Karimullah, 1998. Relevance of management practices in downy mildew in onion. *Sarhad J. Agri.*, **14**:161-162

Ahmed, H.G., Magaji, M.D., Yakutu A.I., Aliyu, L. and Singh, A.2007. Response of garlic (*Allium sativum* L.) to irrigation interval and clove size in semi-arid Nigeria. *J. Pl. Sci.*, **2**:202-208

Al Zahim, M., Newbury, H.J. and Ford Lloyd, B.V. 1997. Classification of genetic variation in garlic (*Allium sativum* L.) revealed by RAPD. *Hort. Sci.*, **32**:1102-1104

Al Zahim, M., Newbury, H.J. and Ford Lloyd, B.V. 1999. Detection of somaclonal variation in garlic (*Allium sativum* L.) using RAPD and cytological analysis. *Plant Cell Rep.*, **18**:473-477

Alam, M.S.M., Rahim, A. and Anwar, H.R.M.M.2000. Effect of planting time and clove size on the growth and yield of garlic. *Bangladesh J. Trg. and Devt*.**13**:1-2

Altaf, H.H., Muhammad, S., Khan. J., Muhammad, I. and Khan, S. 1999. Effects of non- chemical methods and botanical insecticides on onion thrips, *Thrips tabaci* Lind (*Thysanoptera:Thripidae*) in onion crop in Balochistan. *Sarhad J. Agri*., **15**:619-624

Anand, J.C. 1972. The quality of vegetables for processing. *Ind. Food Packer*, **26**:62-64

Ankur, V, Nandal T.R. Ravinder Singh and Vermani A, Singh R.2002. Nutrient uptake and economic weed management in garlic (*Allium sativum* L.*). Ind. J. Weed Sci*. **33**:3-4

Anonymous, 1986. *Annual Report*, Department of Agricultural Research and Education, Govt. of India, p. 47.

Anonymous, 2010. National Horticultural and Research Development Foundation (NHRDF) Database. Available at http://www.nhrdf.com/Content Page.asp?ResultCode=303

Arguello, J.A, Alicia ledesma, SelvaB.Nunez, Carlos and Maria del Diaz.2006. Vermicompost effects on bulbing dynamics, non-structural carbohydrate content, yield and quality of garlic bulbs. *Hortsci.,* **41**:589-592

Arya, M., Barnwal, V.K., Ahlawat, Y.S. and Singh, L. 2006. RT-PCR detection and molecular characterization of onion yellow dwarf virus associated with garlic and onion *Curr. Sci.,* **91**:1230-1234

Arya, P.S. and Bakshi, B.R. 1999. Onion based cropping systems studies under mid-hill conditions of Himachal Pradesh. *Adv. Horti. Forestry.* **6**:79-85

Asha Devi, A. and Khar, A. 2000. Preliminary studies on *in vitro* regeneration from flower bud explants of onion (*Allium cepa* L.). In: *Proceedings of National Symposium on Onion-Garlic production and post harvest management challenges and strategies*, Maharashtra, p.194

Assuncao, I.P., Coclho, R.S.B., Lima, G.S., de-A., Lima, J.A.S. and Tavares, S.C.C., 1999. Reaction of onion cultivators to isolates of *Collectotrichum gloeosporioides* from sub medio San Francisco Region, Brazil. *Summa Phytopathologica,* **25**:205-209

Aswath, C.R., Mo, S.Y., Kim, D.H. and Park, S.W. 2006. *Agrobacterium* and biolistic transformation of onion using non-antibiotic selection marker phosphomannose isomerase. *Plant Cell Rep.,* **25**: 92-99

Ayabe, M. and Sumi, S. 1998. Establishment of a novel tissue culture method, stem disc culture, and its practical application to micropropagation of garlic (*Allium sativum* L.). *Pl. Cell Rep.,* **17**:773-779

Baghalian, K., Naghavi, M.R., Ziai, S.A. and Badi, H.N. 2006. Post-planting evaluation of morphological characters and allicin content in Iranian garlic (*Allium sativum* L.) ecotypes. *Scientia Hort*., **107**:405-410

Baghalian, K., Sanei, M.R., Naghavi, M.R., Khalighi, A. and Badi, H.A.N. 2005. Post-culture evaluation of morphological divergence in Iranian garlic ecotypes. *Acta Hort*., **688**:123-128

Bajaj, K.L., Kaur, G. and Singh, T. 1979. Lachrymatory factor and other chemical constituents of some varieties of onion. *J. Plant Food*. **3**:119-203.

Balasubramayam,V.R.A, Dhake, V. and Moitra, P.2000. Micro Irrigation and fertigation of V-12 Onion. *International conference on micro and sprinkler irrigation systems* held at Jalgaon (Abstr. p.77)

Barandiaran, X., Di Petro A. and Matin, J. 1998. Biolistic transfer and expression of a uid A reporter gene in different tissues of *Allium sativum* L. *Plant Cell Rep.,* **17** : 737-741

Bark, O.H., Havey, M.J. and Corgan, J.N. 1994. Restriction fragment length polymorphism (RFLP) analysis of progeny from an *Allium fistulosum x A. cepa* hybrid. *J. Amer. Soc. Hort. Sci.,* **119**:1046-1049

Barnwal M.K. and Prasad, S.M. 2005. Influence of date of sowing on *Stemphylium* blight disease. *J. Res., Birsa Agriculture University*, **17**:63-67

Barnwal M.K. Prasad, S.M. and Maiti, D. 2003. Efficacy of fungicides and bioagents against *Stemphylium* blight of onion. *Ind. Phytopath.,* **56**:291-292

Barnwal, M.K., Prasad, S.M. and Kumar, S. 2006. Cost effective fungicidal management of *Stemphylium* blight of onion. *J. Res., Birsa Agricultural University,* **18**:153-155

Bertaccini, A., Botti, S., Tabanelli, D., Dradi, G., Fogher, C., Previati, A. and Re, F. da. 2004. Micropropagation and establishment of mite-borne virus-free garlic (*Allium sativum*). *Acta Hort*., **631**:201-206

Bhagchandani, P.M., Netrapal, Singh, N. and Choudhary, B. 1980. White onion for dehydration. *Ind. Horticulture*, **24**:2

Bhangale, G.T. and Joi, M.B. 1983. Role of thrips in development of purple blotch of onion. *J. Maharashtra Agril. Uni.*, **8**:299-300

Bhonde S.R., Sharam, S.B. and Chougale, A.B.1997. Effect of biofertilzer in combination with nitrogen through organic sources on yield and quality of onion. *NHRDF*

News lett. XVII, **2**:1-3

Bhonde, B.R, Srivastava, K.J and Singh, K.N.1987. Effect of different age of seedlings and date of transplanting on yield and quality of onion during *rabi* season. *Annual Report.* Associated Agricultural Foundation, Nahik

Bieri, M., Zwygart, F., Tognina, G. and Stadler, G. 1989. The importance of soil water content for the biological control of *Thrips tabaci* Lind. on cucumbers in greenhouse. Mitteilungen der Schweizerischen Entomologischen Gesellschaften, **62**:28

Bohanec, B. and Jakse, M. 1993. Variations in gynogenic response among long day onion (*Allium cepa* L.) accessions. *Pl. Cell Rep.*, **18**:737-742

Bradley, K.F., Rieger, M.A. and Collins, G.G. 1996. Classification of Australian garlic cultivars by DNA fingerprinting. *Aust. J. Exptl. Agri.*, **36**:613-618

Brar, K.S., Sidhu, A.S. and Chadha, M.L. 1993. Screening onion varieties for resistance to *Thrips tabaci* Lind. and *Helicoverpa armigera* (Hubner). *J. Insect Sci*., **6**:123-124

Brar, P.S and S.P.S. Gill. 2000. Effect of clove size on yield of garlic. *Haryana J. of Hortl. Sci.*, **29**:1-2

Buso, G.S.C., Paiva, M.R., Torres, A.C., Resende, F.V., Ferreira, M.A., Buso, J.A. and Dusi, A.N. 2008. Genetic diversity studies of Brazilian garlic cultivars and quality control of garlic clover production. *Genet. and Mole. Res.,* **7**:534-541

Campion, B., Falavigna, A., Soressi, G.P. and Schiavi, M. 1985. Efforts for *in vitro* androgenesis in onion (*Allium cepa* L.). *Genetica Agraria*., **39**: 315

Campion, B., Perri E., Azzimonti, M.T., Vicini, E. and Schiavi, M. 1995. Spontaneous and induced chromosome doubling in gynogenic lines of onion (*Allium cepa* L.). *Plant Breed.*, **114**:243-246

Cho, K., Eckel,C.S., Walgenbach, J.F. and Kennedy, G.G. 1995. Comparison of coloured sticky traps for monitoring thrips populations (Thysanoptera: Thripidae) in stacked tomato fields. *J. Ent. Sci*., **30**: 176-190

Chopade, S.O, Bansode, P.N and Hiwase, S.S .1998. Studies on fertilizer and water management to onion. *PKV Res. J*., **22**: 44-46

Conci, V.C., Perotto, M.C., Cafrune, E. and Lunello,P. 2005. Program for intensive production of virus-free garlic plants. *Acta Hort*., **688**: 195-200

Corgan, J. and Holland, M. 1993. "NuMex Starlite" onion. *HortScience*, **28**: 66-67

Dang, J.K. and Gupta, P.C. 1984. Chemical control of storage rot of onion bulbs caused by *Fusarium solani*. *Haryana Agric. Uni. J. Res,*. **15**: 403-407

Darshan Singh, D., Sidhu, A.S., Thakur, J.C. and Singh, D. 1986. Relative resistance of onion and garlic cultivars to *Thrips tabaci* Lind. *J. Res. Punjab Agril. Uni.*, **23**: 424-427

Dhiman J.S., Chadha, M.L. and Sidhu, A.S. 1986. Studies on the reaction of onion genotypes against purple blotch. *Veg. Sci.*, **13**:304-309

Dhingra, K.L. and Nariane, T.K. 1963. A virus disease of onion. *Ind. Phytopath.*, **16**:311-312

Diraviam, J. and Uthamasamy, S. 1992. A new sampling technique involving yellow sticky traps for monitoring thrips infesting different crops. *J .Ento. Res*., **16**:78-81

Dunstan, D.I. and Short, K.C. 1978. Shoot production from onion callus tissue cultures. *Sci. Hort.*, **9**:99-110

Eady, C.C., Weld, R.J. and Lister, C.E. 2000. *Agrobacterium* mediated transformation and transgenic plant regeneration of onion (*Allium cepa* L.). *Pl. Cell Rep.*, **19**:376-381

Eady, C.C., Kamoi, T., Kato, M., Porter, N. G., Davis, S., Shaw, M., Kamoi, A. and Imai S. 2008. Silencing Onion Lachrymatory Factor Synthase Causes a Significant Change in the Sulfur Secondary Metabolite Profile. *Plant Physio.*, **147**:2096-2106.

Ebaneb, A.C. 1980. Onion twister disease caused by *Glomerella cingulata* in North Nigeria. *Plant Disease*, **64**:1030-1032

El Gendi, S.M. 1998. Population fluctuation of *Thrips tabaci* Lind. on onion plants under Fayoum environmental conditions. *Arab Univ. J. Agril. Sci.*, **6**:267-276

Etoh, T. 1986. Fertility of the garlic clones collected in Soviet Central Asia. *J. Jpn. Soc. Hort. Sci.*, **55**:312-319

Etoh, T. and Simon, P.W. 2002. Diversity, fertility and seed production of garlic. In: *Rabi*nowitch, H.D., Currah, L. (Eds.), Allium Crop Science : Recent advances. CABI Publishing, New York, pp.101-117

Etoh, T., Watanabe, H. and Iwai, S. 2001. RAPD variation of garlic clones in the center of origin and the westernmost area of distribution. *Mem. Fac. Agric. Kagoshima University*, **37**:21-27

Fajardo, T.V.M., Torres, A.C., Buso, J.A., Avila, A.C., and Resende, R.O.2002. Yield and bulb quality of virus-free garlic. *Summa Phytopathologica*. **28**:207-210

FAOSTAT. 2010. Available at: http://faostat.fao.org/faostat/collections?subset=agriculture

Fellner, M. and Havranek, P. 1994. Culture of protoplasts isolated from leaves and callus cultures of *Allium* *sativum* and *Allium* longicuspis: a preliminary report. *Biologisches-Zentralblatt,* **113**:317-328

Fernandez, S.A. and Lucena, C. 1990. Evaluation of the effect of different coloured sticky traps in attracting *Thrips tabaci* Lindeman (Thysanoptera: Thripidae). *Agronomia Tropical Maracay*, **40**:4-6

Figliuolo, G. and Stefano, D.di. 2007. Is single bulb producing garlic *Allium sativum* or *Allium ampeloprasum*? *Scientia Hort*., **114**:243-249

Figliuolo, G; Candido, V., Logozzo, G., Miccolis, V. and Zeuli, P.L.S. 2001. Genetic evaluation of cultivated garlic germplasm (*Allium sativum* L. and *A. ampeloprasum* L.). *Euphytica*, **121**:325-334

Fischer, D. and Bachmann, K. 2000. Onion microsatellites for germplasm analysis and their use in assessing intra- and interspecific relatedness within the subgenus *Rhizirideum*. *Theor Appl Genet.*, **101**:153-164

Fournier, Francois, Guy Boivin, and Robin Stewart. 1995. Effect of *Thrips tabaci* (Thysanoptera: Thripidae) on yellow onion yields and economic thresholds for its management. *Entom. Soc. Amer.*, **88**:1401-1407

Fritsch, R.M. and Friesen, N. 2002. Evolution, domestication and taxonomy. *Allium* Crop Science : Recent advances. CABI Publishing, New York, pp.5-30

Gangloff, J.L. 1999. Population dynamics and insecticide resistance of onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), in onion. Ph.D. dissertation, Cornell University, Ithaca, NY

Gargi, and Roy, A.N. 1988. Prevention and control of some post harvest fungal disease of garlic bulbs. *Pesticides*, **22**:11-15

Gent, D.H, Schwartz, H.R. and Khosla, R. 2004. Distribution and incidence of IYSV in Colarado and its relation to onion plant population and yield. *Pl. Dis*., **88**:446-452

Girija, G., Pathak, C.S. and Gowda, R.V. 1998. Reaction of onion lines to basal rot disease caused by *Fusarium oxysporum f. sp. cepae*. *PKV Res. J.*, **22**:53-54

Gokce, A.F., McCallum, J., Sato, Y. and Havey, M.J. 2002. Molecular tagging of the Ms locus in onion. *J. Amer. Soc. Hort. Sci.*, **127**:576-582

Gonclaves, P.A.S. 1997. Seasonal fluctuation of thrips, *Thrips tabaci* Lind., on onion in Ituporanga, Santa Catarina. *Anais da Sociedade Entomologica do Brasil*, **26**:365-369

Goto R and Kimoto T.1992. Effect of different organic fertilizers on productivity of summer onion. *Hotl. Brasileria,* **10**:114-115

Gupta, N.K. and Ganeshe, R.K. 2000. Response of borax and zinc sulphate on growth and yield of garlic (*Allium sativum* L.). *Adv. Pl. Sci*., **13**:237-239

Gupta, R.B.L. and Pathak, V.K. 1987. Management of purple blotch *Alternaria porri* (Ellis:) Clif. of onion by summer ploughing and alteration of date of sowing. *Z. Microbiol.*, **142**:163-166

Gupta, R. B. L. and Pathak, V. N. 1988. Induction of sporulation in *Alternaria porri in vitro*. *Curr. Sci.*, **57**: 102

Gupta, R.P. and Pandey, U.B. 1986a. Stemphylium blight of onion. *Ind. Hortic.*, **31**:13

Gupta, R.P. and Pandey, U. B. 1986b. Viral and mycoplasmal diseases of onion in India. *Ind. J. Virol.*, **2**:111-113

Gupta, R.P. and Sharma, R.C. 1998. Effect of new insecticide/biopesticides on control of onion thrips. *News Letter, Natl. Hortl. Res. Found.*, **18**:5-7

Gupta, R.P. and Srivastava, P.K., 1992. Studies on the onion storage diseases in Indian, *AADF Newslett*., **12**:1-13

Gupta, R.P., Srivastava, P.K. and Pandey, U.B. 1983. Efficacy of fungicides against *Fusarium oxysporum* f.sp. *cepae*, incitant of basal rot in onion. *Pesticides*, **17**:16

Gupta, R.P., Srivastava, P.K. and Pandey, U.B. 1986. Control of purple blotch of onion seed crop. *Indian Phytopath.*, **39**:303-304

Gupta, R.P., Srivastava, P.K. and Sharma, R.C. 1996a. Chemical control of purple blotch and *Stemphylium* blight diseases of onion. *NHRDF News letter*, **16**:14-16

Gupta, R.P., Srivastava, P.K. and Sharma, R.C. 1996b. Effect of foliar spray of different fungicides on the control of *Stemphylium* blight disease and yield of onion bulb. *NHRDF News letter*, **16**:13-15

Hamdy, M.K. and Salem, M.1994. The effect of plantation dates of onion temperature and relative humidity on the population density of the onion thrips, *Thrips tabaci* Lind., in Egypt. Annals of Agricultural Science Cairo, **39**:417-424

Havey, M.J. 1991. Phylogenetic relationships among cultivated *Allium* species from restriction enzyme analysis of the chloroplast genome. *Theor Appl Genet.*, **81**:752-757

Hoepting, C.A., Schwartz, H.R. and Pappu, H.R. 2007. First report of Iris Yellow Spot Virus on onion in New York. *Pl. Dis*., **91**:327

Hsu H.C., Hwu, K., Deng, T and Tsao, S. 2006. Study on genetic relationship among Taiwan garlic clones by RAPD markers. *J. Taiwan Soc. Hortl. Sci.*, **52**:27-36

Huchette, O., Kahane, R., Auger, J., Arnault, I. and Bellamy, C. 2005. Influence of environmental and genetic factors on the alliin content of garlic bulbs. *Acta Hort*. **688:**93-99

Ipek, M., Ipek, A., Almquist, S.G. and Simon, P.W. 2005. Demonstration of linkage and development of the first low-density genetic map of garlic, based on AFLP markers. *Theor. Appl. Genet.,* **110**:228-236

Ipek, M., Ipek, A., and Simon, P.W. 2003. Comparison of AFLPs, RAPD markers, and isozymes for diversity assessment of garlic and detection of putative duplicates in germplasm collections. *Hort. Sci.* **128**:246-252

Ipek, M., Ipek, A., and Simon, P.W. 2008. Rapid characterization of garlic clones with locus-specific DNA markers. *Sci. Hort.*, **32**:357-362

Izquierdo,H, Gomez, O. 2005. 'Martinez', a garlic (*Allium sativum* L.) clone with a high yield potential and good behavior against diseases. Cultivos-Tropicales. **26**:53

Jenderek, M.M. 2004. Development of S1 families in garlic. *Acta Hort*., **637**:203-206

Jenderek, M.M. and Hannan, R.M. 2004. Variation in reproductive characteristics and seed production in the USDA garlic germplasm collection. *HortSci*., **39**:485-488

Jenderek, M.M. and Zewdie, Y. 2005. Within and between family variability for important bulb and plant traits among sexually derived progenies of garlic. *HortSci*., **40**:1234-1236

Jones, H.A. and Davis, G.N. 1944. Inbreeding and heterosis and their relation to the development of new varieties of onions. *Tech. Bull. 784*, U.S. Dept. Agri. p. 28.

Jones, H.A. and Emsweller, S.L. 1937. A male sterile onion. *Proc. Am. Soc. Hortl. Sci.*, **34**:582-585

Joshi, H.C. and Tandon, J.P. 1976. Heterosis for yield and its genetic basis in onion. *Ind. J. Agril. Sci.,* **46**:88-92

Kahane, R., Teyssendier de la Serve, B. and Rancillac, B. 1992. Bulbing in long day onion (*Allium cepa* L.) cultured *in vitro*: comparison between sugar feeding and light induction. *Ann. Bot.* **69**:551-555

Kalra, C.L., Beerh, J.K., Manan, J.K., Teotia, M.S. and Sharma, T.C. 1986. Studies on influence of cultivars on the quality of dehydrated onion (*Allium cepa* L.). *Ind. Food Packer*, **40**:20-27

Kamentsky, R., London Shafir, I., Bizerman, M., Khassanov, F., Kik, C. and *Rab*inowitch, H.D. 2003. Garlic (*Allium sativum* L.) and its wild relative from Central Asia : evolution for fertility potential. *Proceeding of XXVIth International Horticultural Congress*, Toronto, Canada. *Acta Hort..*, **673**:83-91

Keller, E.R.J. and Korzun, L. 1996. Haploidy in onion (*Allium cepa*) and other *Allium* species: 51-75. In *In vitro haploid production in higher plants*, S.M. Jain, S.K. Sopory, R.E. Veilleux. (Eds.) Vol. **3**, Kluwer Dordrecht, The Netherlands

Khar, A., Asha Devi, A. and Lawande, K.E. 2005. Callus culture and regeneration from root tip of garlic (*Allium sativum* L.). *J. Spices Arom. Crops*, **14**:51-55

Khar, A., Asha Devi, Lawande, K.E., Mahajan, V. and Kulkarni, P.M. 2000. Evaluation of US and Indian commercial hybrids under Indian conditions. *Allium Improvement Newslett*. **10:** 1-2

Khar, A., Asha Devi, A., Mahajan, V. and Lawande, K.E. 2005. Genotype X environment interactions and stability analysis in elite lines of garlic (*Allium sativum* L.). *J. Spices Arom. Crops*, **14**:21-27

Khar, A., Asha Devi, A., Mahajan, V. and Lawande, K.E. 2006. Genetic divergence analysis in elite lines of garlic (*Allium sativum* L.). *J. Mah. Agri. Univ*., **31**:52-55

Khar A, Bhutani R.D, Yadav N and Chowdhury V.K. 2005. Effect of explant and genotype on callus culture and regeneration in onion (*Allium cepa* l.). *Akdeniz Universitesi Ziraat Fakultesi Dergisi* (Turkey). **18**:397-404

Khar, A., Bhutani, R.D. and Yadav, N.R. 2003. *In vitro* regeneration studies on effect of genotype, explant and media in garlic (*Allium sativum* L.). *Vegetable Sci.,* **30**:138-144

Khar A, Yadav R.C Yadav, N and Bhutani R.D. 2005. Transient GUS expression studies in onion (*Allium cepa* L.) and garlic (A*llium sativum* L.). *Akdeniz Universitesi Ziraat Fakultesi Dergisi* (Turkey), **18**:301-304

Khar, A., Lawande K.E., and Asha Devi, A. 2008. Analysis of genetic diversity among Indian garlic (*Allium sativum* L.) cultivars and breeding lines using RAPD markers. *Ind. J. of Genet. Pl. Breed.*, **68**:52-57

Khar, A., Mahajan,V., Devi, A.A. and Lawande, K.E. 2005. Genetical studies in elite lines of garlic (*Allium sativum* L.). *J. Mah. Agri. Univ*., **30**:277-280

Khare, V.K. and Nema, K.G. 1982. Factors affecting germination of spores of *Alternaria porri in vitro* and *in vivo*. *Ind. Phytopath*., **35**:100-103

King, J.J., Brandeen, J., Bark, O., McCallum, J. and Havey, M.J. 1998. A low density genetic map of onion reveals a role for tandem duplication in the evolution of an extremely large diploid genome. *Theor. Appl. Genet.*, **96**:52-56

Kofoet, A. and Zinkernagel, V. 1990. Resistance to downy mildew (*Peronospora destructor*) in *Allium* species. *Z. Pflanzenkr. Pflanzenschutz*, **97**:13-23

Kotgirwar, V.V, M.H. Chaudhari, M.M. Damke and B.J.Jadhao.1998. Effect of planting methods and clove size on growth, yield and quality of garlic cv. 'Godawari'. *PKV Res. J.*, **21**:182-184

Koul, A.K., Gohil, R.N. and Langer,A. 1979. Prospects of breeding improved garlic in the light of its genetic and breeding systems. *Euphytica*, **28**:457-464

Koycu, N.D. and Ozer, N. 1997. Determination of seed borne fungi in onion and their transmission to onion sets. *Phytoparasitica*, **25**:25-31

Kubota, S. 1999. Effectiveness of *Beauveria bassiana* against *Thrips palmi* on musk melons in a greenhouse. *In*: *Procs. Kansai Pl. Prot. Soc.*, **41**:69-70

Kumar, S., Sharma, J.P. Kumar, A. Sarkar, A.K. and Sharma, V.N. 2001. Yield, quality attribute and *Pseudomonas* bulb rots influenced by nitrogen, boron, potassium and fly ash application in acid soil. *In*: Recent Trends in Horticultural Research (Eds. Mathura Rai, S. Kumar, Ranvir Singh and V.S.R. Krishna Prasad), Horticultural Society of Chotanagpur, Ranchi, pp. 270-275

Lallan Singh, Mishra, V.K., Chougule, A.B. and Singh, L.1996.Effect of size of planting material and spacing on yield and quality of garlic variety Agrifound White. *NHRDF News letter*, **16: 3**, 1-3;

Lampasona, S.G., Martinez, L., and Burba, J.L. 2003. Genetic diversity among selected Argentinean garlic clones (*Allium sativum* L.) using AFLP (Amplified Fragment Length Polymorphism). *Euphytica*, **132**: 115-119

Larentzaki, K., Shelton, A.M, Musser, F.R., Nault, B.A. and Plate, J. 2007. Overwintering locations and hosts for onion thrips (*Thysanoptera: Thripidae*) in the onion cropping ecosystems in New York. *J. Econ. Entomol*, **109**:1194-1200

Larentzaki, K., Shelton, A.M. and Plate, J. 2008. Kaolin particle film on *Thrips tabaci* (Thysanoptera: Thripidae) oviposition, feeding and development on onions. A lab and field case study. Crop Production, **27**:727-734

Latha, S., Sathyanaryana, N. and Reddy, O.R. 2007. Interception of *Embellisia allii* in garlic bulbs imported from China. *Ind. Phytopath.*, **60**:125-127

Lawande, K.E. 2005. Onion improvement – Present status and future thrust. In: Souvenir, "National Symposium on current trends in onion, garlic, chillies and seed spices- production, marketing and utilization, 25-27 Nov., 2005, pp. 1–11 NRCOG, Rajgurunagar, Pune, Maharashtra.

Lee, E.M., Ra, S.W., Lee, J.Y., Min, S.R., Song, N.H. and Lee, Y.B. 1988. The effect of growth regulators and the conditions of stock bulb storage on callus growth of garlic in vitro. *Res. Rep. Rural Devl. Admn. Hort*., **30**:90-95

Li, C.H., Li, X.C., Zhao, M.H. and Zhao, J.L. 1995. Studies on the virus free technology of meristem tip and tissue culture in *Allium sativum*. *Acta Agricultura Boreali Sinica*, **10**: 20-25

Lorbeer, J.W. 1990. Botrytis leaf blight of onion *In*: Diseases of International Importance Vol. III (Eds: H.S. Chaube, J. Kumar, A.N. Mukhopadhyay and U.S. Singh), Prentice Hall USA. pp. 186-209

Lu, F.M. 1990. Colour preference and using silver mulches to control onion thrips, *Thrips tabaci* Lindeman. *Chinese J. Entom.*, **10**:337-342

Lu, Q.Y., Zhou, W.Y. and Dong, Y.Y. 1982. Induction of callus from young leaves of garlic and plantlet regeneration. *Acta Hort. Sinica*, **9**:67-69

MaaB, H.I. and Klaas, M. 1995. Interspecific differentiation of garlic (*Allium sativum* L.) by isozymes and RAPD markers. *Theor. Appl. Genet.*, **9**:89-97

Madalgeri, B.B. and Bojappa, K.M 1986. Heterosis in a diallele cross in onion. *Ind. J. Horti*. **43**:108-111

Maini, S.B., Diwan, B. and Anand, J.C. 1984. Storage behaviour and drying characteristics of commercial cultivars of onion. *J. Food Sci. & Tech*., **21**:417-419

Majumdar, S., Arya, M., Pant, R.P. and Baranwal, V.K. 2007. Shallot Virus X in Indian shallot, new report for India. *New Dis. Rep.*, **15** : 52.

Mani, V.P., Chauhan, V.S., Joshi, H.C. and Tandon, J.P. 1999. Exploiting gene effects for improving bulb yields in onion. *Ind. J. Genet. Pl. Breed.*, **59**:511-514

Marikhur, R.K., Dhar, A.K. and Kaw, M.R. 1977. Downy mildew of *Allium cepa* and its control with fungicides in Kashmir Valley. *Ind. Phytopath.*, **30**:576-577

Masuda, K., Hatakeyama, E., Ito, A., Takahashi, S. and Inoue, M. 1994. Micropropagation of garlic (*Allium sativum* L.). *Bull. Akita Prefectural College of Agriculture*, **20**:43-48

Mathur, K., Gurjar, R.B.S., Sharma. S.N. and Sharma, K 2007. Efficacy of fungicides, Bio-agent and plant extract against pink root rot disease of onion induced by *Fusarium solani*. *J. Mycol. Pl. Pathol.* **37**:523-524

Mathur, K., Sharma, S.N. and Sain, R.S. 2006. Onion variety RO-59 has higher yield and resistance to purple blotch and *Stemphylicum* blight. *J. Mycol. Pl. Pathol.*, **36**:49-51

Maude, R.B. 1989. Seed borne diseases of onion and their control. *Onion Newslett. Trop.*, **1**:16-18

Melo-Filho,-P-de-A; Resende,-R-O; Cordeiro,-C-M-T; Buso,-J-A; Torres,-A-C; Dusi,-A-N. 2006. Viral reinfection affecting bulb production in garlic after seven years of cultivation under field conditions. *Eur. J. Pl. Pathol*., **116**:95-101

Mohamed Yasseen, Y., Barringer, S.A. and Splittstoesser, W.E. 1995. *In vitro* bulb production from *Allium* spp. *In vitro Cell. Dev. Biol.,* **31**:51-52

Mohammad, M.J. and Zuraiqi S. 2003. Enhancement of yield and nitrogen and water use efficiencies by nitrogen drip fertigation of garlic. *J. Pl. Nutrition*. **26**:1749-1766

Mohanty, B.K., Hossain, M.M. and Pruthi, A.M. 2000. Varietal assessment of common onion for horticultural traits during *kharif* season. *Orrisa J. Hort.,* **28**:8-11

Moniz, L. and Bhinde, V.P. 1964. Three new bacterial diseases of plants from Maharastra. *Ind. Phytopath.,* **17**:146-153

Moniz, L. and Patel, M.K. 1958. Three new bacterial diseases of plant from Bombay State. *Curr. Sci.,* **27**:494-495

Muren, R.C. 1989. Haploid plant induction from unpollinated ovaries in onion. *HortSci.,* **24**:833-834

Murphy, B.C., Morisawa, T.A., Newman, J.P., Tjosvold, S.A. and Parrella, M.P. 1998. Fungal pathogen controls thrips in greenhouse flowers. *Calif. Agri*., **52**:32-36

Nabulski, I., Safadi A.I., Mit, B., Ali, N. and A*rabi*, M.I.E. 2001. Evaluation of some garlic (*Allium sativum* L.) mutants resistant to white rot disease by RAPD analysis. *Ann. Appl. Biol.*, **138**:197-202

Nam S, Choi In, H., Bae S.K. and Bang J.K., 2007. Effect of irrigation level on plant growth and bulb yield during bulb development stage of garlic plants. *Korean J. Hortl. Sci. and Tech.,* **25**:169-173

Novak, F.J. 1980. Phenotype and cytological status of plants regenerated from callus cultivars of garlic (*Allium sativum* L.). *Pl. Sci. Lett.,* **34**:250-260

Novak, F.J. 1990. *Allium* tissue culture. *In*: H.D. *Rabi*nowitch and J.L. Brewster (eds.). Onions and allied crops, CRC Press, Boca Raton, Fla., pp. 234-250

Pal, N. and Singh, N. 1999. Heterosis for yield and storage parameters in onion (*Allium cepa*). *Ind. J. of Agril. Sci*., **69**:826-829

Palti, J. 1989. Epidemiology, production and control of downy mildew of onion caused by *Perasospora destructor*. *Phytoparasitica*, **17**:1

Pandey, 1989. Onion (*Allium cepa* L). *Ind. Hort*., **33-34**:58-62

Pandotra, V.R., 1965. Purple blotch disease of onion in Punjab II: Studies on the life history, viability and infectivity of the causal organism *Alternaria porri*. *Proc. Ind. Acad. Sci. Sec. B,* **61**:326-330

Panthee, D.R., Regmi, H.N., Subedi, P.P., Bhattarai, S. and Dhakal, J. 2006. Diversity analysis of garlic (*Allium sativum* L.) germplasm available in Nepal based on morphological characters. *Genet. Res. Crop Evol*., **53**:205-212

Paredes, C.M., Becerra, V.V. and Gonzalez, A.M.I. 2008. Low genetic diversity among garlic (*Allium sativum* L.) accessions detected using random amplified polymorphic DNA (RAPD). *Chilean J. Agril. Res.,* **68**:3-12

Park, M.Y., Yi-NaRi; Lee-HanYong; Kim-SungTae; Kim-MinKyun; Park-JuHyun; Kim-JuKon; Lee-JonSeob; Cheong-JongJoo; Choi-YangDo., 2002. Generation of chlorsulfuron-resistant transgenic garlic plants (*Allium sativum* L.) by particle bombardment. Mol.-Breed., **9**:171-181

Patel, J.C, Raghvani B.R, Khanpara V.D, Kavani H.D and Malavia D.D.1985. Comparative efficiency of herbicides for weed control in onion. Abstracts of papers, *Ann. Conference Ind. Soc. Weed Sci.,* p. 21, Tamil Nadu Agricultural University, Coimbatore

Patel, P.N. 1972. Bacterial diseases of plants in India. ICAR, New Delhi

Patel. B.G., Khanpara, V.D., Malavia, D.D., Maraviya R.B. and Kaneria B.B. 1996. Economic feasibility of drip irrigation in garlic. *Ind.. J. Agron*., **45**:143-145

Pathak, C.S., Singh, D.P., Deshpande, A.A. and Sreedhar, T.S. 1986. Sources of resistance to pruple blotch in onion. *Veg. Sci.,* **13**:300-303

Pathak, C.S., Singh, D.P. and Deshpande, A.A. 1986. A new type of cytoplasmic male sterility in onion (*Allium cepa* L.). *First All India Conference of Cytology and Genetics*, Bangalore University, December 1986, Abst. pp. 13

Pawar, C.Y, U.S. Kadam, S.D. Gorantiwar and S.P. Pampattiwar, 1998. Efficacy of the micro sprinkler irrigation method for garlic. *J. Mah. Agril. Univ*. **23**:156-159

Pena Iglesias, A. and Ayuso, P. 1982. Characterisation of Spanish garlic viruses and their elimination by *in vitro* shoot apex culture. *Acta Hort.,* **127**:183-193

Pike, L.M., Horn, R.S., Andersen, C.R., Leeper, P.W. and Miller, M.E. 1988a. 'Texas Grano 1015Y' a mild pungency, sweet, short day onion. *HortSci.,* **23**:634-635

Pike, L.M., Horn, R.S., Andersen, C.R., Leeper, P.W. and

Miller, M.E. 1988b. 'Texas Grano 1015Y' a mild pungency, sweet, short day onion. *HortSci.*, **23**:636-637

Qasem, J.R.1996. Weed competition in garlic (*Allium sativum* L.). *J. Hortl. Sci.*. 1996, **71**:41-48

Rahman, M.A., Chiranjeevi, C.H. and Reddy, I.P. 2000. Management of leaf blight disease of onion. Proc. National Symposium on Onion Garlic Production and Post Harvest Management. Challenges and strategies, November 19-21, 2000, Nasik (India) pp. 147-149

Raina, B.L., Teotia, M.S., Pruthi, J.S. and Kalra, C.L. 1988. Studies on the evaluation of some new onion cultivars for their suitability for dehydration. *Ind. Food Packer*, **42**:7-14

Rajasab A.H. and Rao. C.V. 1992. *Aspergillu niger* van Tiegh the causal organism of black mold of onion. *J. of Aerobiol.*, pp.127-132

Rajendran, K. and Rangnathan, K. 1996. Biological control of basal rot (*Furasium oxysporum f. sp. cepae*) by combined application of fungal and bacterial antagonists. *J. Biol. Control*, **10**:97-102

Raju, K.S. and Raj, R.B. 1980. Soft rot of onion in storage. *Madras Agril. J.*, **67**:194-195

Ramamoorthy K, Selvaraj K.V and Velayutham ,A.2000. Effect of irrigation and nitrogen levels on bulb yield of small onion (*Allium cepa* L.). *Madras Agri. J.*. **86**:140-141

Ramniwas, D.K., Singh, R.A. and Goutam.1998. A note on the effect of clove, planting distance and GA on the growth and yield of garlic. *Orissa J. Horti.*, **26**:72-74

Rath, G.C. and Mohanty, G.N. 1986. *Fusarium* rot of stored garlic. *Ind. Phytopath.*, **39**:614-615

Ravi, K.S., Kitkaru, A.S., Winter, S. 2006. Iris yellow spot virus in onions: a new tospovirus record from India, *Pl. Path.*, **55**:288

Reddy, K.C and Reddy, K.M, 2005. Differential levels of vermicompost and nitrogen on growth and yield in onion *(Allium cepa L.)* radish (*Raphanus sativus* L.) cropping system. *J. Res., ANGRAU*. **33**:11-17

Remiro, D. and Kirmati, H. 1975. Control of seven curls disease of onion with benomyl. *Sum. Phytopathology*, pp. 51-54

Resende, G.M-de, Chagas, S.J-de R, Pereira, L.V., 2003. Productive and qualitative characteristics of garlic cultivars. *Horticultura-Brasileira*, **21**:686-689

Rosales-Longo, F.U, Molina-Monterroso, L.G., 2007. Genetic diversity of the garlic (*Allium sativum* L.) grown in Guatemala, revealed by DNA markers. *Agronomia-Mesoamericana*, **18**: 85-92

Rumpel, K.S and Dysko, J. 2003.Effect of drip irrigation and fertilization timing and rate on yield of onion. *J. Veg. Crop Prod.*, **9**:65-73

Saha U.K, Khan, M.S.I, Haide J and Saha R.R., 1997. Yield and water use of onion under different irrigation schedules in Bangladesh. *Jap. J. Trop. Agri.*, **41**:268-274

Saimbhi, M.S. and Bal, S.S. 1996. Evaluation of different varieties of onion for dehydration. *Punjab Veg. Grower*, **31**:45-46

Saimbhi, M.S. and Randhawa, K.S. 1982. Losses in white onion variety Punjab-48 under ordinary storage conditions as influenced by bulb size. *J. Res. India*, **19**:188-190

Saimbhi, M.S., Padda, D.H. and Singh, G. 1970. Evaluation of onion varieties for dehydration traits. *J. of Food Science & Tech*., **8**:149-150

Sankar, V and Lawande, K.E., 2009. Standardization of suitable planting material for successful cultivation of garlic. *Spice India*, **22:**17-21

Sankar, V, Qureshi, A.A, Tripathi, P.C. and Lawande, K.E., 2005. Production Potential and Economics of Onion Based Cropping Systems under Western Maharashtra Region. Paper presented on *National symposium on current trends in onion, garlic, chillies and seed spices– production, marketing and utilization, (SYMSAC-II)*, November 25-27, Rajgurunagar, Pune, Abstr. p 79

Sankar, V., Veeraragavathatham, D. and Kannan, M. 2009. Organic farming practices in white onion (*Allium cepa* L.) for the production of export quality bulbs. *Journal of Ecofriendly Agriculture*, **4**:17-21

Sankar, V., Lawande, K.E. and Tripathi, P.C. 2008. Effect of micro-irrigation practices on growth and yield of garlic. *J. Spices Arom. Crops*. **17**:232-234

Sankar, V., Tripathi, P.C., Qureshi, A. and Lawande, K.E. 2005. Fertigation studies in onion and garlic. *National symposium on current trends in onion, garlic, chillies and seed spices– production, marketing and utilization, (SYMSAC-II)* November 25-27, Rajgurunagar, Pune, (Abstr. pp. 62 & 80)

Sastry, K.S. 1980. Plant Virus and Mycoplasmal Diseases in India - A Bibiliography. Bharati Publ. Delhi, 270

Sawahel, W.A. 2002. Stable genetic transformation of garlic plants using particle bombardment. *Cellular and molecular biology letters*. **7**:49-59.

Scott, S.J., McLeod, P.J., Montgomery, F.W. and Hander, C.A. 1989. Influence of reflective mulch on incidence of thrips (Thysanoptera : Thripidae : Phlaeothripidae) in stacked tomatoes. *J. Entom. Sci*., **24**:422-427

Seabrook, J.E.A. 1993. *In vitro* propagation and bulb formation of garlic. *Can. J. Pl. Sci.,* **74**:155-158

Selvaraj, N, Natarajan, S, Selvarajan, V.M, Sudha Mathews and Pabitha. A. 2002. Effect of foliar application of micronutrients on the growth and yield of garlic. *S. Ind. Hort.,* **50**:159-168

Sen, B. and Srivastava, S.N. 1957. Utilization of cytoplasmic male sterility on production of hybrid onion seeds. *In*: *Proc. 44th Ind. Sci. Congress*. pp. 225

Senula, A., Keller, E.R.J. and Leseman, D.E. 2000. Elimination of viruses through meristem culture and thermotherapy for the establishment of an *in vitro* collection of garlic (*Allium sativum*). *ActaHort*., **530**:121-128

Sharangi, A.B, Pariari, A, Datta, S and Chatterjee, R .2003. Effect of boron and zinc on growth and yield of garlic in New Alluvial Zone of West Bengal. *Crop Research,* **25**:83-85

Sharma, A.B, Patel, R.K and Tiwari, J.P. 1983. Chemical weed control in garlic. *Ind. J. Weed Sci.*, **15**:17-22

Sharma, I.M. 1997. Screening of onion varieties/lines against purple blotch caused by *Alternaria porri* under field conditions. *Pl. Dis. Res.*, **12**:60-61

Shashidhar, T.R., and Dharmatti, P.R. 2005. Genetic divergence studies in garlic. *Karnataka J. Hort*., **1**:12-15

Shelton, A.M., Nault, B.A., Plate, J. and Zhao, J.Z. 2003. Regional and temporal variation in susceptibility to lambda cyclothrin in onion thrips in onion field of New York. *J. Econ. Entomol.*, **96**:1843-1848

Shinde, N.N and Sonatakke, M.B.1986. Onion, *In*: Bulb crops, *Vegetable crops in India*. (Bose, T.K. and Som. M.G. Eds), Naya Prokash, Calcuttas, pp. 544-592

Shock, C.C., Ishida, J.K., Eldredge, E.P. and Seddigh, M. 2000. Yield of yellow onion cultivars in eastern Oregon and southwestern Idaho. *HortTech.*, **10**:613-620

Shuaib O.S.B. 2001. Critical period for weed competition in onions (*Allium ceap*L.). *J. Natural and Appl Sci.,* **5**:355-360

Simon, P.W. and Jenderek, M.M. 2003. Flowering, seed production and the genesis of garlic breeding. *Pl. Breed. Rev.,* **23**:211-244

Simon, P.W. and Jenderek, M.M, 2004. Flowering, seed production, and the genesis of garlic breeding. *Pl. Breed. Rev*., **23**:211-244

Singh, D.P and Singh, R.P.1974. Studies on the effect of time of sowing and age of seedlings on growth and yield of onion. *Ind. J . Hort* ., **31**:69-73

Singh, B and Singh R.P.1990. Studies on chemical weeding in onion. *Veg. Sci.,* **7**:14-17

Singh, R., Nandal, T.R., Singh, R. 2002. Studies on weed management in garlic (*Allium sativum* L.). *Ind. J. Weed Sci.,* **34**:80-81

Singh, B. M. and Sharma, Y. R. 1977a. Rust on garlic. *FAO Pl. Prot. Bull.,* **25**:41-42

Singh, B.M. and Sharma, Y.R. 1977b. Occurrence of leaf blight of garlic caused by *Stemphylium botryosum* in India. *Ind. Phytopath.*, **30**:272-273

Singh, R.P. 2007a. New record of white leaf spot of onion. *National Research Centre for Onion and Garlic News.* **11**:4

Singh, R.P. 2007b. New record of *Curvularia spp.* on onion. *National Research Centre for Onion and Garlic News,* **11**:3

Singh, R.P. 2007c. Some uncommon diseases of onion: smudge. *National Research Centre for Onion and Garlic News,* **11**:5

Singh, R.P. 2008. Black scurf of onion: A New Report. *National Research Centre for Onion and Garlic News,* **12**:2

Singh, R.P. and Khar, A. 2007. First report of *Embellisia alli* from garlic. *National Research Centre for Onion and Garlic New*s, **11**:4

Singh, U.P. and Singh, R.B. 1984. Differential responses of host and non-host substrata on germination of ascospores of *Sclerotinia sclerotiorum*. *Phytopathologische Zeitschrift,* **110**:277-280

Sinha, B.B.P., Sinha, R.K.P., Asghar, S.M.A. and Singh, A.P. 1998. Perfect stage of *Stemphylium vesicarium* on garlic. *J. Appl. Biol.,* **8**:82-83

Sinha, R.K.P., Singh, A.P., Sinha, B.B.P. and Asghar, S.M.A. 1995. *Stemphylium* blight: a new fungal disease of garlic. *J. Appl. Biol.*, **5**:93

Srinivas P.S., Anil Khar, Aziz Qureshi, and K.E. Lawande 2007. Wild alliums as sources of resistance to *Thrips tabaci*. In. Proceedings of III National Symposium on Plant Protection in Horticulture: Emerging trends and challenges, 7-9 March 2007, IIHR, Bangalore

Srinivas, P.S. and Lawande, K.E. 2000a. Efficacy of certain botanicals in management of onion thrips. In. Proceedings of The National Symposium on onion-Garlic Production and Post-Harvest Management: Challenges and Strategies, November, 19-21, 2000, Nashik, p. 219

Srinivas, P.S. and Lawande, K.E. 2000b. Economics in management of onion thrips. In. Proceedings of The National Symposium on onion-Garlic Production and Post-Harvest Management Challenges and Strategies, November, 19-21, 2000, Nashik. p.219.

Srinivas, P.S. and Lawande K.E. 2004. Impact of planting dates on *Thrips tabaci* Lindeman infestation and yield loss in onion (*Allium cepa* L.). *Pest Mgt. Hortl. Ecosyst*, **10**:11-18

Srinivas, P.S. and Lawande K.E. 2006. Maize barrier as a cultural method for management of thrips in onion (*Allium cepa* L.). *Ind. J. Agril. Sci*., **76**:167-71

Srinivas P.S. and Lawande K.E.. 2007. Seedling root dip method for protecting onion plants from thrips. *Ind. J. Pl. Protection*, **35**:206-209

Srinivas, P.S. and Lawande K.E. 2008. Growth stage susceptibility of onion (*Allium cepa* L.) and its role in thrips management. *Ind. J. Agril. Sci*, **78**:98-101

Srinivas, P.S., Singh R.P. and Lawanda K.E. 2007. Integrated Pest and Disease Management in Onion and Garlic. Tech. Bull. No.17, National Research Centre for Onion and Garlic, Rajgurunagar, 410 505, Maharastra, India, pp 34

Srivasatva, M.P. 1978. Nursery protection in vegetables. Haryana Kheti, **19**:9

Srivastava, R, Ankur Agarwal, Tiwari, R.S. and Santosh Kumar, 2005. Effect of micronutrients, zinc and boron on yield, quality and sto*rabi*lity of garlic (*Allium sativum*). *Ind. J. Agril. Sci.,* **75**: 157-159

Srivastava, K.J. and Quadri, S.M.H. 1984. Some studies on damping-off disease of onion *(Allium cepa* L.*). Ind. Bot., Reptr.,* **5**:194

Srivastava, P.K. and Pandey, V.B. 1995. Compendium of onion diseases. Tech. Bull. No.7, NHRDF, Nasik, 26 pp

Srivastava, P.K., Sharma, R.C. and Gupta, R.P. 1995. Effect of different fungicides on the control of purple blotch and *Stemphylium* blight diseases in onion and seed crop. *NHRDF Newsletter,* **15**:6-9

Srivastava, P.K., Tiwari, B.K., Srivastava, K.J. and Gupta, R.P. 1996. Chemical control of purple blotch and basal rot diseases in onion bulb crop during *Kharif*. *NHRDF Newslett. Hortl. Found.,* **16**:7-9

Storsberg, J., Schulz, H. and Keller, E.R.J. 2003. Chemotaxonomic classification of some Allium wild species on the basis of their volatile sulphur compounds. *J. Appl. Bot*., **77**:160-162

Sugha, S.K., Develash, R.K. and Tyagi, R.D. 1992. Performance of onion genotypes against purple blotch pathogen. *South Ind. Hort.,* **40**:297

Sugha, S.K., Tyagi, P.D. and Develash, R.K. 1993. Effect of heat treatment of bulb and spray of fungicides in management of purple blotch (*Alternaria porri*) of onion (*Allium cepa*). *Ind. J. Agril. Sci.*, **63**:303-305

Suh, S.K. and Park, H.G. 1986. Studies on the anther culture of garlic (*Allium sativum* L.). 1: Callus formation and plant regeneration. *J. Korean Soc. Hortl. Sci.,* **27**:89-95

Suh, S.K. and Park, H.G., 1995. Plant regeneration from the culture of garlic root explants. *J. Korean Soc. Hortl. Sci.,* **36**:31-37

Suresha, B.A, Allolli T B, Patil M.G, Desai B.K and Hussain S.A. 2007. Yield and economics of chilli based intercropping system. *Karnataka J. Agri. Sci.,* **20**:807-809

Swamy, T.C.N. and Narayana, S.T.C. 1983. Tissue culture multiplication of chillies (*Capsicum annuum* L.) and onion (*Allium cepa* L.). Thesis Abstracts, **9**:340-341

Swarup, J., Nagaroti, M.S. and Saksena, H.K. 1973. A new bacterial stalk rot of onion caused by *Pseudomonas allicola* in India. *Ind. J. Mycol. Pl. Pathol.,* **3**:187-189

Swarup, V. 1990. Onion improvement in India. In: *Proceedings of National Symposium on onion and garlic*, NRCOG, Rajgurunagar, Pune, pp. 21-32

Tamil Selvan C, Valliappan K and Sundararajan R.1990.Studies on the weed control efficiency and residues of oxyfluorfen in onion (*Allium cepa* L.). *Intl. J. Trop. Agri.,* **8**:123-128

Tapia, V.M. 1991. Meristematic root tubercles: a new explant obtained by *in vitro* culture of garlic (*Allium sativum* L.). *Agro Ciencia,* **7**:5-10

Thilakavathy, S. and N. Ramaswamy. 1998. Effect of inorganic and biofertilizer treatments on yield and quality parameters of multiplier onion. *NHRDF Newslett.* **XVIII**:18-22

Tizio, R. 1979. Garlic flowering *in vitro*. *Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences D,* **289**:401-404

Tommasini, M.G., Maini, S. and Nicoli, G. 1997. Advances in the integrated pest management in protected eggplant crops by seasonal inoculative releases of *Orius laevigatus*. *Adv. Hortl. Sci*., **11**:182-188

Toor, RF-Van, Till, C.M., James, D.E. and Teulon, D.A.J. 2004. Evaluation of UV reflective mulches for protection against thrips (*Thrips tabaci*) in onion (*Allium cepa*) crops. New zealand Plant Protection, **57**:209-213

Upadhyay, J. and Tripathi, K.C. 1995. Field evaluation of fungicides against purple blotch of onion seed crop. *Rec. Hort.,* **2**:153-155

Upmanyu, S. and Sharma, R.C. 2007. Seed yield loss in onion by purple blotch (*Alternaria porri*) and its management. *Ind. Phytopath.* **60**:370-372

Van Heusden, AW., Van Ooijen, J.W., Vrielink van Ginkel, R, Verbeek, W.H.J., Wietsma W.A and Kik, C. 2000. A genetic map of an interspecific cross in *Allium* based on amplified fragment length polymorphism (AFLP™) markers. *Theor. Appl. Genet.*,**100**:118-126

Vidal, B.C., Mello M.L.S, IIIg., Campos, R.D., Vidal, B., Campos, de DE. and Vidal, B. 1993. Chromosome number and DNA content in cells of a biotechnologically selected somaclone of garlic (*Allium sativum* L.). *Revisita Brasileira de Genetica,* **16**:347-356

Vinay Singh, J, Bisen R.K, Agrawal H.P and Singh, V. 1997. A note on weed management in onion. *Veg. Sci.,* **24**:157-158

Volk, G.M., Henk, A.D. and Richards, C.M. 2004. Genetic diversity among U.S garlic clones as detected using AFLP methods. *J. Am. Soc. Hortl. Sci.,* **129**:559-569

Wang, H.L., Kang, Y.Q. and Zhang, C.J. 1994. Embryogenesis *via* culture of garlic sprout leaf. *Acta Agri. Boreali Sinica,* **9**:92-94

Warade, S.D, Shinde, S.V. and Gaikwad, S.K.1996. Studies on periodical storage losses in onion. *Allium News letter*, **10**:37-41

Warid, W.A. and Loaiza, J.M. 1996. Attributes of onion yield in twelve cultivars of short day onions. *Onion Newslett. Tropics,* **7**:22-24

Warriach, K.M., Hussain, T., Talpur, M.A., Khuhro, I.U, Ahmad, M (ed.), Shakoori, A.R. 1994. In. Proceedings of Pakistan Congress of Zoology, Vol. 12, Twelfth Pakistan Congress of Zoology, Lahore, April, 1992. **1994**:471-475

Xu, P., Yang, C., Qu, S. and Yang, C.Y. 2005. A preliminary study on genetic analysis and purity assessment of the garlic germplasm and seed bulbs by the "fingerprinting" technique. *ActaHort*., **688**:29-33

Yang, F., Liu, S. and Wang, X. 2005. Effects of boron in soil on the physiological-biochemical characteristics, yield and quality of garlic. *Sci.Agricultura Sinica*. **38**:1011-1016

Zewdie, Y. and Jenderek, M.M. 2005. Within and Between-family variability for important bulb and plant traits among sexually derived progenies of garlic. *Hort. Sci.,* **40**:1234-1236

Zheng, S.J., Khrustaleva, L., Henken, B., Sofiari, E., Jacobsen, E., Kik, C. and Krens, FA. 2001. *Agrobacterium tumefaciens* mediated transformation of *Allium cepa* L.: The production of transgenic onions and shallots. *Mol. Breed.,* **7**:101-115

Zhila, E.D. 1981. Correlations between phenotypic traits in garlic of the bolting type. *Tsitologiya-i-Genetika*, **15**:46-48