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Review Article

Pomegranate the Cash Crop of India: A Comprehensive Review on Agricultural Practices and Diseases

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ABSTRACT

Pomegranate (*Punica granatum*) is most adapted subtropical fruit crop, which was introduced in India during 15th century from the Mediterranean region. India is largest grower, producer and exporter of pomegranate since last decade. Among eight major pomegranate growing states, Maharashtra is the largest producer, occupies 70.2% of total area in the country with average productivity of 13.24 MT. In recent years, there is decline in production in Maharashtra due to a disease like anthracnose caused by *Colletotrichum* sp. *Colletotrichum* causes the infection on all plant parts as sub circular or angular black lesions results in stem deformation, defoliation during shoot development, death of inflorescences, necrotic lesions on leaves. The productivity has decreased though the land coverage has increased in last decade. Under unfavorable climatic conditions this disease has caused yield loss of up to 100%. This review sheds light on the production, agricultural practices, crop biology and diseases of pomegranate causing crop losses. It highlights the epidemiology, symptoms and management strategies for common diseases in pomegranate. It has been observed that, due to monoculture practices and change in environment, the disease like anthracnose causes tremendous losses. Therefore, it warrants urgent consideration for developing new agricultural practices and effective methods to eradicate the disease.
Keywords: Pomegranate, Anthracnose, *Colletotrichum* sp., Disease management

1. INTRODUCTION

Fruits are major source of nutrition as well as sustainable income for farmers. Presently in India, 7.2 million hectare area is under fruit crops cultivation which produces 88.9 million tons of fruits with 12.3MT productivity. India contributes more than 30% share in total production of horticulture (Horticultural Statistics at a Glance, 2015). India stands at second position with 13.6% share in world's total fruit production (Indian horticulture database, 2014).

In the course of the most recent decade, the region under horticulture production raised with the rate of 2.7% per annum and yearly production expanded by 7.0%. During 2013-14 annual growth of fruit production was highest (9.5%) as compared to aromatics, flowers, crops, spices and vegetables production. The leading fruit growing states in India are Maharashtra which accounts for 15.0% of total fruit production by whole country, followed by Andhra Pradesh (12.0%), Gujarat (9.0%), Tamil Nadu (8.0%), Karnataka (8.0%), Uttar Pradesh (8.0%), Madhya Pradesh (6.0%), Telangana (5.0%), Bihar (5.0%), and West Bengal (21.0%) (Horticultural Statistics at a Glance, 2015).

Banana is the major fruit accounting for 33.4% of total production followed by mango (20.7%), citrus (12.5%), papaya (6.3%), guava (4.1%), grape (2.9%), apple (2.8%), sapota (2.0%), pineapple (2.0%), pomegranate (1.5%), litchi(0.7%) and others (11.1%) in India (Indian horticulture database, 2014).

Among all, Pomegranate is known as most adaptable, perishable, subtropical fruit crop with increased cultivation. It was acquainted from the Mediterranean territory to Africa, Asia, Europe and Indian promontory. At first, it was grown in Indonesia of Indian peninsula amid the 15th century, reported by Levin (2006a).

At present, Afghanistan, Bangladesh, Chile, China, Cyprus, Egypt, France, Greece, Georgia, India, Iran, Iraq, Israel, Italy, Lebanon, Mexico, Morocco, Myanmar, Portugal, Spain, Syria, Tajikistan, Thailand, Tunisia, Turkey, Turkmenistan, the USA and Vietnam, are some Pomegranate growing countries in the world for table use and as an ornamental tree (Mars, 1996; Tous and Ferguson, 1996).

Among these China, India, Iran, Turkey and the USA are five major producers of Pomegranate contributing 76% of total production from all over the world. However, Spain, Egypt and Israel are leaders in export and research by developing several new varieties of pomegranate (Quiroz, 2009).

Table 1: Total Pomegranate production in India during last ten years.

Year	Area (in 000' ha)	Area over 2005-06 (in %)	Production (in 000' MT)	Production over 2005-06 (in %)	Productivity	Productivity Over 2005-06 (in %)
2005-06	116	-	849	-	7.3	-
2006-07	117	0.86	840	- 1.06	7.2	- 1.36
2007-08	122	5.17	884	4.12	7.2	- 1.36
2008-09	109	- 6.03	807	- 4.94	7.4	1.36
2009-10	125	7.75	820	- 3.41	6.6	- 9.58
2010-11	107	- 7.75	743	- 12.48	6.9	- 5.47
2011-12	112	- 3.44	772	- 9.06	6.9	- 5.47
2012-13	113	- 2.58	745	- 12.24	6.6	- 9.58
2013-14	131	12.93	1346	58.53	10.3	41.09
2014-15	143	23.27	1774	108.95	12.4	69.68

Source: www. nhb.gov.in

Table 2: Total Pomegranate production in Maharashtra during last ten years.

Year	Area (in 000' ha)	Area over 2005-06 (in %)	Production (in 000'MT)	Production over 2005-06 (in %)	Productivity	Productivity over 2005-06 (in %)
2005-06	91.0	--	593.6	--	6.5	--
2006-07	92.5	1.64	601.5	1.33	6.4	- 1.53
2007-08	90.5	- 0.54	596.2	0.43	6.2	- 4.61
2008-09	82.0	- 9.89	550.0	- 7.34	6.7	3.07
2009-10	98.9	8.68	555.5	- 6.41	5.6	- 13.84
2010-11	82.0	- 0.108	492.0	- 17.11	6.0	- 7.69
2011-12	82.0	- 9.89	478.0	- 19.47	5.8	- 10.76
2012-13	78.0	- 14.28	408.0	- 31.26	5.2	- 20.0
2013-14	90.0	- 1.09	945.0	59.19	10.5	61.53
2014-15	99.14	8.94	1313.4	121.25	13.24	103.69

Source: www.nhb.gov.in

India stands first in the list of Pomegranate producer countries with respect to cultivation area. The leading pomegranate growing states of India are Maharashtra (70.2%), Karnataka (10%), Gujarat (7.4%), Andhra Pradesh (6.7%), Telangana (1.9%), Madhya Pradesh (1.9%), Tamil Nadu (1.0%) and Rajasthan (0.4%) (Horticultural Statistics at a Glance, 2015). Maharashtra occupies 66.67% of total pomegranate farming area. The scenario of pomegranate production in India and in Maharashtra state during past few years is portrayed in table 1 and table 2 respectively. Among all pomegranate producing countries, India is the biggest exporter of pomegranate from the most recent decade as its fruits are of edible quality and available almost throughout the year. Table 3 represents the data about export of pomegranate from India in past few years. According to the horticulture database of India, it has become the biggest exporter of pomegranate to entire world and UAE, Netherlands, Saudi Arabia and Bangladesh are major importing countries of pomegranate from India. Due to its increasing demand and export value around the world, it is considered as one of the "Vital Cash Crop" of India. This review covers the important aspects of Pomegranate crop including its production scenario, crop biology, agricultural practices, common diseases and strategies available for their management.

Table 3: Statistics of export of Pomegranate from India.

Year	Quantity (in Tons)	Value (in Lakh)
2005-06	19652.1	5670.15
2006-07	21670.4	7957.30
2007-08	35175.1	9119.49
2008-09	34811.2	11461.61
2009-10	33415.0	11942.84
2010-11	18211.7	7095.19
2011-12	30162.2	14727.82
2012-13	36027.4	23449.61
2013-14	31328.2	29851.62
2014-15	20937.0	32361.45
2015-16	310723.6	41599.77

Source: DGCIS, Annual export: https://www.agriexchange.apeda.gov.in/product search/pomegranate (Last visited on 28/3/17)

2. Biology of Pomegranate

Pomegranate; fruit bearing shrubs or trees comes under small genus of *Punica*. Although, earlier placed in monogeneric family *Punicaceae*, now it has been shifted to family *Lythraceae* by the Angiosperm Phylogeny Group (APG IV, 2016) based on phylogenetic studies (Graham *et al.,* 2005). Including *Punica* there are 32 genera and about 620 species of flowering plants in this family. *Punica* is a minor genus with only two species named as *Punica protopunica* and *Punica granatum*. Among these two, the better known species is *P. granatum* and based on the color of ovary it has been subdivided into two sub species, that are Chlorocarpa and Porphyrocarpa. In pomegranate, color of ovary is a steady attribute that is held even when reproduction occurs by seeds. The chromosome number varies among different cultivars of pomegranate; 2n=16 or 18 (Levin, 2006a).

The pomegranate tree is an attractive, perennial tree of 6-10 m (20 to 30 ft) in height, although some are dwarf (1-2m) and has bushy appearance. It has smooth and often quadrangular stem with dark grey bark at maturity (Teixeira da Silva *et al.,* 2013). Leaves are1-10 cm long, evergreen or deciduous, opposite or sub opposite, petiolate, simple, entire, exstipulate, oblong or obovate, glossy, glabrous, glandular, exist in whorls of 5 or 6 and usually remain crowded on short lateral shoots (Lawrence, 1951; IBPGR,1986; Morton, 1987). Flowers are actinoid, hermaphrodite, terminal or axillary single or sometimes five in a cluster. They are three centimeter wide, funnel shaped, red to brilliant orange in color and distinguished by cylindrical, thick, meaty calyx with five to eight lobes. They contain five to seven lanceolate, wrinkled, red or white variegated petals which enclose numerous stamens, dorsifixed anthers, colporate pollen grains and inferior ovary (Morton, 1987; El Kassas *et al.,* 1998; Teixeira da Silva *et al.,* 2013). Two flowering seasons have been observed in pomegranate cultivars which are gown in North India while those of Central and Western India has three blooming seasons viz. Ambe bahar (January-February), Mrig bahar (June-July) and Hasta bahar (September-October) as reported by Nalwadi *et al.* (1973). The fruit is nearly round, 5-12 cm in diameter with a prominent thick calyx. Fruit pericarp (skin or rind) is glossy, coriaceous and hard, differs in surface color among cultivars from yellow with a dark red cheek to strong caramel red and splendid red. Mesocarp (albedo, the spongy tissue) is separated into a few chambers by a horizontal diaphragm and vertical septal films which are comprised of papery tissue. Each and every chamber is packed with transparent sacs, filled with several arils (number varies among cultivars but may be as high as 1300 per fruit) which represent about 52% weight of the whole fruit (Lawrence, 1951; Purseglove, 1968; Dahlgren and Thorne, 1984; Morton, 1987; Levin, 2006b). The palatable part of the fruit is known as arils, which are fleshy, flavorful, juicy, red or pink in color and not attached to the septal membrane (Morton, 1987; Watson and Dallwitz, 1992). Wild type pomegranate fruits are acidic, whereas cultivated cultivars have sweet to sour flavor. Fruits get ripe after 6-7 months of flowering, developed a unique color and produce metallic sound after tapping.

Pomegranate is self-pollinated as well as cross pollinated crop in which the size and fertility of pollens vary as per the season and cultivar (Pross, 1938; Nalwadi *et al.*, 1973; Jalikop and Kumar, 1990). From all over the world, hundreds of cultivars have been characterized on the basis of aril color, flower type, fruit size, rind color, resistance to biotic and abiotic factors, sugar and acid content in fruit, shelf life of fruit, seed hardness and yield. (Harlan, 1992; Hancock, 2004; Levin, 2006a; Holland *et al.,* 2009). Interestingly, huge genetic diversification has been observed among 500, globally distributed varieties of pomegranate, out of which around 50 are commercially cultivated (IPGRI, 2001). Some significant, Indian varieties of pomegranate having commercial value are Ganesh, Jalore, Khandhari, Kabul, Mridula, Bhagwa, G-137, Arka Ruby, Jyoti, Amildana, Alandi, Dholka etc (Hiwale, 2009).

3. Agronomic Practices

3.1 Climatic conditions

Mediterranean environment with cool winters and hot summers is most favorable for Pomegranate but it can be grown in tropical or subtropical humid environment. It can easily withstand temperature up to 45^{o}C-48^{o}C in combination with dry hot winds but optimum temperature is 38^{o}C. Mature plant can tolerate frost when it is in dormant phase but, young tree up to three years of age is injured by early or late winter frost due to temperature less than -11^{o}C (Badizadegan, 1975; Morton, 1987; Patil and Shewale, 2003). The pomegranate crop has long growing season of about 4-7 months and requires hot and dry atmosphere amid fruit development and aging. It is a drought tolerant, winter hardy crop which flourishes well under arid climate. High temperature with sufficient time duration is required for development of sweet fruits. (Halilova and Yildiz, 2009). Southern India has preferred arid climate for pomegranate cultivation hence; quality fruits are available throughout the year. While in other pomegranate producing countries around the world, availability is confined to a shorter and specific period in a year. In Spain, fruits are available during August to March, in the USA from August to November and in Peru from April to July (Jalikop *et al.,* 2006; Kulkarni and Dethe, 2006; Kotikal *et al.,* 2009). It requires annual rainfall of 500-800mm.

3.2 Soil type

The pomegranate can develop on differing sorts of soil however prefers profound loamy or alluvial soil which is prolific, wealthy in humus, have medium thickness with great seepage. It grows best in neutral soil (pH 5.5-7.0) but can tolerate soil alkalinity up to pH 7.5 and active lime concentration between 12-15%. Although, it is a salt tolerant plant but excess accumulation of salts in soil (more than 0.5%) is harmful (Wang, 2003). According to Indian Horticulture database (2013) pomegranate plant can withstand salinity up to 9.00 EC/mm (electrical conductivity per millimeter) and sodicity 6.78 ESP (exchangeable sodium percent). It produces quality fruits in medium or light black soils of at least 60 cm deep. In major pomegranate growing areas of Maharashtra the crop is grown in black, red, gravel and rocky lands of sub marginal and dry areas (Chandra *et al.,* 2006; NRCP, 2007a; 2008; 2009). Adequate moisture in soil is recommended throughout the growing season which contributes to reduction in splitting, growth and production (LaRue, 1980; Sharma *et al.,* 2006).

3.3 Irrigation

Regular irrigation (weekly in summer and biweekly in winter) is recommended to obtain higher fruit yield whereas irregularity results into formation of cracked fruits (Badizadegan, 1975;

Kulenkanp *et al.,* 1985; Levin, 2006b). Implementation of different irrigation schedules during spring and autumn seasons was also suggested by Intrigliolo *et al.,* (2011) as they observed a considerable difference in leaf photosynthesis and stomatal conductance of pomegranate trees which were grown under different irrigation regimes. Drip irrigation and bed or basin irrigation strategies are usually implemented by farmers for pomegranate crop. Drip irrigation has proven to be more effective for proper growth of trees compared to basin irrigation because of slow and even distribution of water through plastic micro tubes. Additionally, it saves water, cost of labor, reduces soil erosion and provide space for intercropping (Chopade *et al.,* 2001; NRCP, 2007b; 2008; 2009; Patil and Bachhav, 2009). Over irrigation causes adverse effects on the crop yield by favoring the growth of field pathogens due to increased humidity and moisture. Continuous flowering is observed in pomegranate plant when watered regularly and quite frequently. Fruits are available from these plants throughout the year which is economically undesirable. To regulate this “Bahar treatment” is given in which irrigation is with hold for two months prior to normal flowering period. This treatment is helpful to get better quality fruits during a particular period in a year.

3.4 Nutritional requirement

Application of farmyard manure (10-20 Kg/tree) alongwith chemical fertilizers, salts of micronutrients (Zn, Mn, B, Fe, Cu each in 15-25 g/Plant), vermi-compost (3-5 Kg/ plant) and Neem Cake (1-3 Kg/plant) is commonly practised by farmers to provide various required macro and micronutrients to pomegranate crop. The type and dose of chemical fertilizers which need to be applied varies among cultivars and geographic location of farm, like zinc is the only required nutrient in California whereas, in Isarail, nitrogen and potassium fertilizers has to be added in equal amount for pomegranate crop (LaRue, 1980; Blumenfeld *et al.,* 2000). Split application of fertilizers in February, May and September is suggested to improve plant vigour hence, the yield. Annual supply of nitrogen fertilizer alone is suffecient for many pomegranate crops and if added in excess it affects the fruit maturity and color. In contarst to this, Bose *et al.,* (1988) reported that higher levels of nitrogen enhance juice and rind percentage of fruit yet decline TSS and TSS/TA proportion.The dose of fertilizers/plant/year (FYM and N:P:K) for important Indian cultivars of pomegranate is recommended by the National Hoticulture Board and summerized in table 4.

Table 4: Recommended dose of fertilizers for Indian pomegranate cultivars.

Age of plant (in years)	Dose of Fertilizer/Plant/Year			
	FYM(kg)	N(g)	P(g)	K(g)
2	5	250	125	125
3	10	500	125	250
4	20	500	125	250
5	20	500	125	250
Above 5	30-40	625	250	250

FYM: Farm Yard Manure; N: nitrogen; P: phosphorus; K: potassium

Foliar application of micronutrients not only helps to maintain nutrient balance in soil but also convenient for field use and induces very rapid plant response (Obreza *et al.,* 2010; Fernandez *et al.,* 2013). Foliar spray of Urea and Calcium chloride resulted into increase in aril size, diameter, weight and length of fruit and ascorbic acid content. Similarly, enhanced growth, yield and fruit quality was obtained through treatment of proline and tryptophan (Ramezanian *et al.,* 2009; El Sayed, 2014).

Intercropping is practised by Indian farmers since long time ago to acquire technical as well as economic benefits from either both the component crops or atleast one in comparsion to monocrop system. Wasaki *et al.,* (2003) reported that intercropping improves mobilization of nutrients in the rhizosphere thus, resulted into better growth and yield from component crops. Green compost crops, pulses and vegetables are recommended as intercrop till the main crop attain 4-5 years age.

Sharma *et al.*, (2015) reported that Pomegranate-Urd-Pea intercrop sequencing improve the availability of macro and micronutrients as well as microbial population in soil as compared to pomegranate monoculture. Increased microbial activity resulted into higher concentration of carbon and nitrogen which lead to better growth of plants (Chirinda *et al.*, 2008). Maity *et al.*, (2014) observed improvement in uptake of potassium and phosphorus (47.47% and 63.44% respectively) by plants growing in soil inoculated with *Penicillium pinophilum*.

4. Diseases and Pests of Pomegranate

Table 5: Important pests and diseases of Pomegranate.

Diseases caused by insect pests				
Name of disease	Causal organism	Symptoms	Affected plant part	References
Pomegranate fruit borer (Pomegranate butterfly)	*Virachola Isocrates*	Cater-pillars puncture the fruit and feed on arils.	Fruit	NHB database, 2012
Bark eating cater pillar	*Indarbela tetraonis*	Pest pierces the stem of tree and feed inside it.	Stem	NHB database, 2012
Stem borer	*Aleurodes* sp.	This pest makes a hole in the main trunk of the tree and feeds on the stems.	Stem	NHB database, 2012
Pomegranate whitefly	*Siphoninus phillyreae*	Yellowing of leaves, short growth and defoliation of leaves in extreme cases.	Leaf	NHB database, 2012
Aphids	*Aphis punicae*	Chlorotic patches on leaves.	Leaves	NHB database, 2012
Mealy Bugs	*Drosicha mangiferae*	Sap sucking mealy bug secretes some droplets on fruits as its feeding activity, on which black or dark brown sooty mould can grow. As a result fruit drop occur.	Fruit	NHB database, 2012
Scale insects	*Saissetia nigra*	Insect feed on fruits and tender shoots by sucking cell sap, causes drying of shoot. The severe invasion may prompt to drying of whole tree.	Fruit	NHB database, 2012
Flat mite	*Brevipalpus lewisi*	Causes rusting and checking on fruit	Fruit	Stover and Mercure, 2007
Leaf roller	*Platynola stultana*	Causes rusting and checking on fruit	Fruit	Stover and Mercure, 2007
Diseases caused by fungal and bacterial pests				
Alternaria fruit spot	*A. alternata*	Tiny, round spots, red to brown in color on the surface of fruits and leaves.	Fruits and leaves	Ezra *et al.*, 2010
Alternaria internal black rot	*A. alternata, A. tenuissima* and *A. arborescens*		Fruits	Tziros *et al.*, 2008
Heart rot	*Aspergillus niger*	Black sporulating fungus inside the fruits causes decay of fruit skin. Arils & skin color changes to brown & pale respectively.	Fruits	Yehia, 2013
Fruit rot	*Alternaria* Sp., *Fusarium* Sp., *and Aspergillus niger*	Symptoms are similar to heart rot, fruit rot and fruit spot.	Fruits	Munhuweyi *et al.*, 2016
Grey mould rot	*Botrytis cinerea, Botrytis spp.*	Grayish mycelium causes rot of whole fruit.	Fruits	Munhuweyi *et al.*, 2016
Wilt	*Ceratocystis fimbriata, Fusarium oxysporum, Rhizoctonia*	Yellowing and withering of leaves causes death of plant in a few weeks.	Leaves	Munhuweyi *et al.*, 2016
Anthracnose	*Colletotrichum gloeosporioides*	Round to sporadic, dark brown spots with depressed centers, resulting in fruit decay	Complete plant	Munhuweyi *et al.*, 2016
Fruit rot	*Cytospora punicae*	Apoplexy collar rot	Fruits	Ammar and El-Naggar, 2014
Blue mould fruit rot	*Penicillium implicatum*	Water-doused regions on fruit surface, followed by development of green to blue green powdery mould. Tainted regions are tan or grey when cut.	Fruits	Munhuweyi *et al.* 2016
Fruit rot	*Penicillium* sp., *Botrytis cinerea, Coniella granati,*	Fruit decay	Fruits	Palavouzis *et al.*, 2015
Die back and fruit rot, dry rot	*Coniella granati*	Decay of aerial parts of tree and growth of fruiting bodies around the fruit.	Fruits	Munhuweyi *et al.* 2016
Shoot blight (stem canker)	*Neofusicoccum parvum*	Blighted shoots having cankers on stem, prompts to death of whole tree.	Stem	Kc and Vallad, 2016
Leaf spot or blight	*Xanthomonas axanopodis pv punicae*	Dark brownish, circular to sporadic water doused spots on leaves and fruits. Under extreme invasion premature defoliation occur.	Complete plant	Munhuweyi *et al.* 2016

Plant pathogens and diseases caused by them is a major reason for crop losses which are occurring worldwide. Successful cultivation of pomegranate has met with a huge economic loss because of diseases and pest attack in recent years. A summary of various diseases caused by fungi, bacteria and other pests on pomegranate is outlined in table 5. Some common diseases which affect pomegranate crop severely and have major contribution in yield loss are described comprehensively in following paragraphs.

4.1 Anthracnose disease

Anthracnose is a fungal disease characterized by variety of symptoms like leaf spots, defoliation, blighted shoots, blotches or distortion, twig canker and dieback. It is caused by different species of *Colletotrichum*, a fungus which covers a broad host range of deciduous and evergreen trees, shrubs, fruits, vegetables, various legumes, and turf grass. Farmers face huge economic loss due to incidences of anthracnose disease as 10-80% reduction in marketable yield of total crop production has been reported (Ashwini and Srividhya, 2012).Whole plant is affected by this disease and finally die due to severe infection. Up to 80-100% loss in overall yield has been recorded for lemons, sweet oranges (Goes and Kupper, 2002), olives, sorghum (Ali *et al.,* 1987; Thomas *et al.,* 1996) and strawberries (Denoyes and Baudry, 1991). Remarkable decrease in photosynthetic activity is reported in affected plants which led to diminution in yield (Makambila, 1978; Theberge, 1985; Obilo and Ikotum, 2009). Information about the etiology and severity of anthracnose on different plants of economic significance is compiled and represented in table 6 which shows; fungus *Colletotrichum* sp. has a very broad host range. Pomegranate cultivation have been used to bear a major loss in fruit quality and yield, mainly due to anthracnose disease. Surveys were conducted in various districts of Karnataka (Nargund *et al.,* 2012) and Maharashtra states of India (Chavan and Dhutraj, 2017) in the year 2009-2010 and 2013-2014 respectively to analyze the extent of damage due to anthracnose. Disease symptoms were observed on all parts of plant but the maximum PDI was reported on fruits (28.80%), followed by leaves (23-24%). Similarly, incidences of anthracnose had been reported in all major pomegranate cultivating countries around the world. Thus, anthracnose presents a threat to pomegranate plantation and demands a higher level of concern. Therefore, this review emphasizes on important aspects of anthracnose disease. Pomegranate anthracnose is beset by *Colletotrichum gloeosporioides* Penz. and Sacc. which belongs to phylum Ascomycete and Coeleomycetes class of Fungi imperfectii (Dean *et al.,* 2012). On PDA medium; *C. gloeosporioides* initially develops mycelia of white to grey in color which becomes pink to orange due to formation of conidia. It is circular in shape with regular margin and shows radial pattern of growth. The conidia are cylindrical with both apices rounded, pink to orange in color and vary in size from 7.57-15.50 × 3.38-7.52 µm (Chowdappa *et al.,* 2012).

4.1.1 Physical factors for disease development

Incidences of anthracnose had been detected from all pomegranate growing countries around the world but their percentage is higher in countries having tropical or subtropical environment like India. The fungus remains latent during hot summer and cool winter seasons in or outside seeds, in soil or in garden debris. It starts infecting developing shoots and young leaves during spring and flourishes very well in rainy season (Moral *et al.,* 2009). Moisture is required for infection on the plant and for germination of conidia. Direct influence of environmental factors had been observed on disease occurrence and expansion. Interestingly, change in weather condition could change the behavior of pathogen and host, as well as the interaction between them (Davis *et al.*, 1987; Coakley *et al.*, 1999). Several authors reported that temperature between 20°C-30°C and relative humidity from 80-95% for 12 hrs are necessary for initial invasion and its development (Prakash, 1996; Roberts *et al.*, 2001; Pandey *et al.*, 2012). Furthermore, dispersal of conidia occurs primarily through water by rain splash, wind, insects and garden tools (Fitzell *et al.*, 1984; Guyot *et al.*, 2005).

S. No.	Name of plant	Name of *Colletotrichum* species	% Damage	Reference
1	Mango (*Mangifera indica*)	*C. gloeosporioides*	60	Kumari *et al.*, 2017
2	Chilli (*Capsicum annum)*	*C. novaezelandiae, C. siamense*	12-50	Damm *et al.*, 2012; Sharma and Shenoy, 2014
3	Banana (*Musa* sp.)	*C. musae*	30-40	Ranasinghe *et al.*, 2003
4	Coffee (*Coffea arabica*)	*C. kahawae*	60-80	Mouen Bedimo *et al.*,2012
5	Avocado (*Persea americana*)	*C. gloeosporioides, C.boninense, C. godetiae*	Up to 70	Hernandez- Lauzardo *et al.*, 2015
6	Tomato (*Solanum lycopersicum*)	*C. agaves, C. dracaenophilum*	-	Farr *et al.*, 2006
7	Alfalfa (*Medicago sativa*)	*C. americaeborealis*	-	Damm *et al.*, 2014
8	Rubber (*Hevea brasiliensis)*	*C. annellatum*	-	Damm *et al.*, 2014
9	Sugar cane (*Saccharum officinarum)*	*C. falcatum*	-	Alexander and Viswanathan 1996
10	Strawberry (*Fragaria* sp.)	*C. fragariae*	-	Howard *et al.*, 1992
11	Watermelon (*Citrullus lanatus*)	*C. lagenarium*	-	Dean and Kuc, 1987
12	Muskmelon (*Cucumis melo*)	*C. lagenarium*	-	Dean and Kuc, 1987
13	Papaya (*Carica papaya*)	*C. gloeosporioides*	75	Saini *et al.*, 2016; Paulla *et al.*, 1997
14	Pomegranate (*Punica granatum)*	*C. gloeosporioides*	40-90	Mandhare *et al.*,1996
15	Guava (*Psidium guajava*)	*C. simmondsii*	-	Singh *et al.*, 2007

Table 6: Etiology and severity of Anthracnose on different plants.

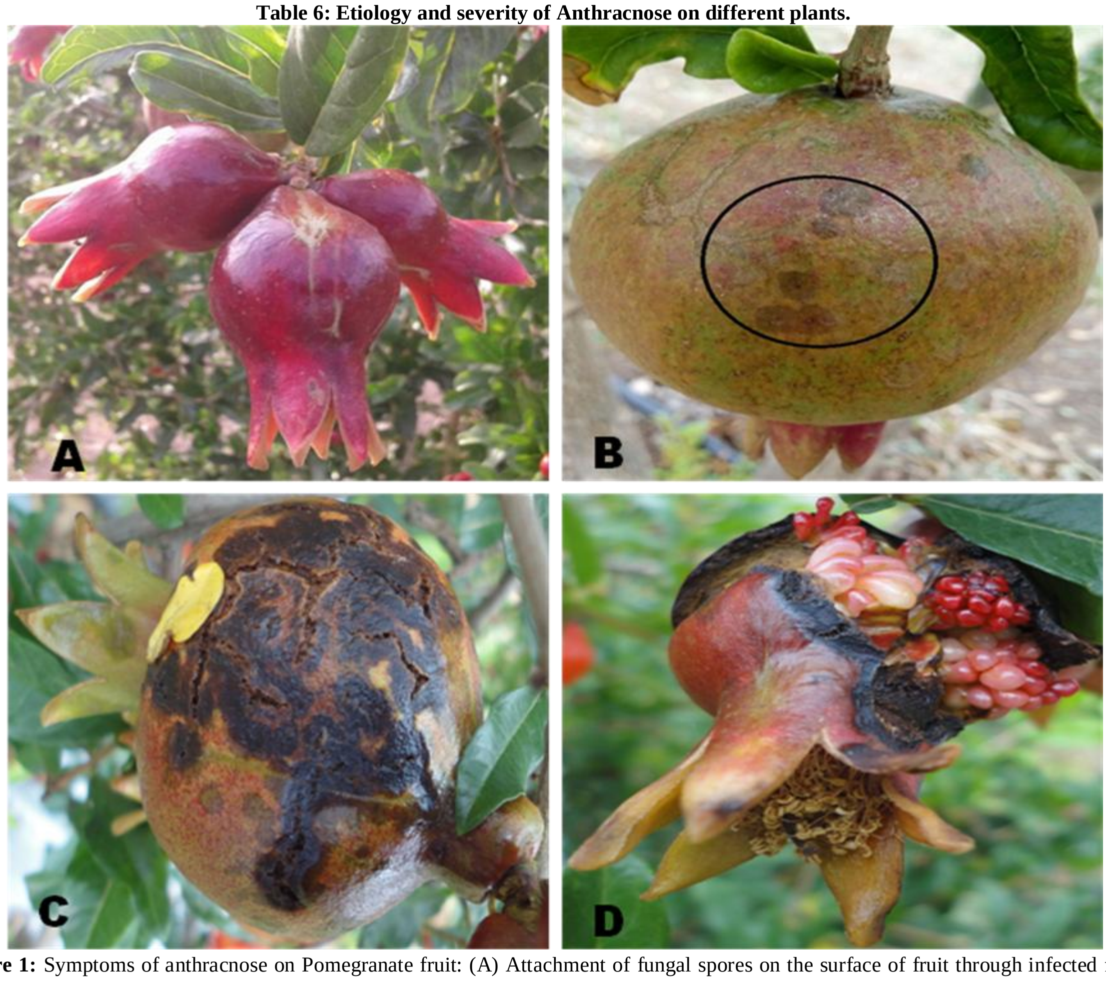

Figure 1: Symptoms of anthracnose on Pomegranate fruit: (A) Attachment of fungal spores on the surface of fruit through infected fruits, water splash, wind, insect etc., (B) Initial stage: Distinguished by sub circular or angular, small, sunken, water doused lesions, surrounded with translucent light brown margins. (C) Intermediate stage: Identified by the nearness of black hued spots in concentric rings which become hard at development. Lesions can coalesce and become necrotic, as fruit grows cracking of peel occur, (D) Final stage: Tainted fruits dry up and transmit conidia (asexual spores) of pathogen to the next season.

4.1.2 Disease symptoms

The pathogen infects whole plant and produces broad symptoms which vary from one cultivar to another. Characteristic symptoms are stem rot, blighted shoots, leaf spot, defoliation, blotches, seedling blight and dieback (Pasin *et al.,* 2009). On fruit, observed symptoms are recognized as sub circular or angular, small, sunken, water doused lesions, surrounded by light brown margins and at advanced stage of infection lesion appears as expanded necrosis (Robert *et al.,* 2001; Pujari *et al.,* 2013). Figure 1 depicts the characteristic, observable symptoms which appeared on pomegranate fruit due to infection of *Colletotrichum gloeosporioides*. The course of penetration, invasion and destruction is rapid to the point that when side effects are perceived, the yield is in genuine threat (Nutman and Roberts, 1960). It affects the fruit quality, marketability and a successful cultivation of pomegranate is converted into a waste within a short span of time (Mendgen and Hahn, 2002; Rodriguez- Lopez *et al.,* 2009; Prusky *et al.,* 2013).

4.1.3Disease cycle

In general, disease cycle is defined as a cascade of events which occur in a sequential manner and repeated continuously in the same fashion. In case of *Colletotrichum*, disease cycle begins with the attachment of fungal conidia on the airy parts of the plant. It consists of multiple, consecutive steps like germination of conidium, production of adhesive appressoria (crucial for cuticle penetration), penetration into the host cell, mycelial growth and development on host tissue, formation of acervuli containing fungal spores for further spread (Prusky *et al.,* 2000; Wharton and Dieguez- Uribeondo, 2004; Arroyo *et al.,* 2005; Gomes *et al.,* 2007; Mota- Capitao *et al.,* 2008). The processes of infection and interaction with their hosts have been studied for several species of *Colletotrichum*. They are categorized either as an intracellular hemibiotrophic phase, a subcuticular intramural phase, or as a blend of both the processes (Bailey *et al.,* 1992; Saxena *et al.,* 2016). No report is available which describes the mechanism adopted by *C. gloeosporioides* to infect host plant (pomegranate). Therefore, the disease cycle described here is of *C. destructivum* which causes anthracnose disease in tobacco. Similar infection mechanism may be predicted for *C. gloeosporioides* on the basis of its taxonomic relationship with *C. destructivum* (Shew and Lucas; 1991). The fungi reported to adopt an intracellular, hemibiotrophic phase in which initially biotrophic phase is trailed by a catastrophic necrotrophic phase at later period of infection (Latunde-Dada *et al.,* 1996). The infection process of *C. destructivum* on tobacco leaves was studied and reported by Shen *et al.* (2001). Following events were observed to occur in a sequential manner (i) Attachment and germination of conidia on the host cell surface, (ii) Penetration of epidermal cell by appressorium or penetration peg, (iii) Formation of multi-lobed infection vesicle, the growth of this infection vesicle is limited up to initially infected host cells, (iv) Emergence of secondary hyphae from primary infection vesicle which colonizes new cells and tissues, (v) Formation of acervuli containing conidia on the plant surface, (vi) Spread of infection. In above mentioned process steps (i) to (iii) were characterized as biotrophic phase of infection and step (iv) was designated as the beginning of necrotrophic phase.

Anthracnose is mainly transmitted through conidia (asexual spores) like other fungal diseases. Despite the fact that appressoria, hyphal parts and appressorium like thick walled cells may also transmit the disease (Nair *et al.,* 1983). Conidia are produced in a slimy matrix and easily dispersed through water, air current, insects or any other form of contact with infected plant part (Yang *et al.,* 1990; Agostini *et al.,* 1993; Ntahimpera *et al.,*, 1999; Mouen Bedimo *et al.,* 2012; Ali *et al.,* 2016). Disease transmission is also possible through mother plant by using infected cuttings as planting material. Over wintered shoots, infected leaves, mummified fruits on the tree or on the soil surface are main source of inoculum for the primary infection. As a result of digging, washing and transplanting exercises, conidia may wash down from the infected upper parts of the plant and facilitates root infection (Peres *et al.,* 2005). It is reported that the conidia of *Colletotrichum gloeosporioides* on infected stems pieces or on the soil surface survive for two dry seasons (Boland *et al.,* 1995).

4.2 Leaf spot or blight

Analogous to anthracnose, significant yield loss in pomegranate is reported due to leaf spot or blight disease (Petersen *et al.,* 2010). It is a bacterial infection caused by *Xanthomonas axonopodis* pv. *punicae* which is a gram negative, flagellate, non-sporulating, aerobic, polar bacterium. On nutrient agar medium; colonies of this bacterium are shiny, mucoid and yellow in color. Dark brownish, circular to sporadic water doused spots on leaves and fruits are characteristic symptoms of the disease. Under extreme invasion premature defoliation occur. (Jadhav and Sharma, 2011, Kalyan *et al., 2012*).

4.3 Alternaria fruit spot

This disease is beset by *Alternaria alternata* and identified by brown, circular, small, and reddish spots on fruits. At the advanced stage, these spots merged to form larger patches and rotting started in fruits. The affected arils change color from red to pale yellow and become unfit for consumption. Infected fruits must be collected and destroyed to prevent the spreading of disease. The spray of mancozeb solution at 0.25 % concentration is suggested to control the disease (Indian Horticulture Database, 2012).

4.4 Wilt

The wilt in pomegranate is produced by different fungal genera like *Ceratocystis fimbriata*, *Fusarium oxysporum* and *Rhizoctonia*. It is associated with yellowing of plants, drying of branches followed by flower and fruit drop. In severe cases the entire orchard is wilted. Since the infection is soil borne, it is essential to maintain soil fertility through judicious irrigation and application of farmyard manure and neem cake. Treatment with copper oxychloride and *Trichoderma* powder (10-15kg/ha) was observed to be powerful against wilt.

4.5 Fruit borer (Pomegranate butter fly)

This disease is caused by an insect named as *Virochola isocrates.* Infestation starts from flower and spread up to fruits. Cater-pillars puncture the fruits and feed on arils. Further, bacteria and fungi grow on damaged fruits as secondary source of infection; cause fruit rotting. Collection and proper disposal of affected fruits is suggested to prevent the blowout of disease. Application of carbaryl (4g $l^{-1}$of water) or phosphamidon (0.3ml $1^{-1}$of water) at 10-15 days intervals is recommended to control the disease.

4.6 Bark eating cater pillar

The causative agent of bark eating cater pillar is *Indarbela tetraonis*, an insect pest, which pierce the stems of tree and feed inside it. Due to this trees are devitalized and unable to bear fruits. The disease is successfully controlled through sanitation, removal of unwanted twigs and cleaning of the affected portions. Plugging of holes with cotton soaked in carbon disulphide or Kerosene or petrol, reduces the disease incidences by preventing insect entry into the bark.

4.7 Whitefly

Whitefly is a serious matter of concern as it is reported in all pomegranate growing areas around the world including India and causes significant crop loss. The disease is caused by an insect i.e. *Siphoninus phillyreae*. Infection begins from the lower surface of apical leaves (after laying eggs by female fly) and then transferred to the upper part of the leaves and fruits. Honeydew, a liquid secreted by whitefly, causes a serious damage to crop and supports bacterial and fungal growth which results into development of secondary infections. Thus, the entire plant is damaged severely and production is affected. Whitefly disease is characterized by yellowing of leaves and stunted growth; during severe invasion defoliation of leaves occur. Mechanical and chemical methods are commonly practiced to get rid of from whiteflies. In mechanical method use of splendid yellow sticky trap is common to catch flies. Water spray with high volume and pressure under the leaves surface; helps in washing out honeydew, eggs, larvae, pupae and adult whitefly. This should be followed by spray of triazophos 40 EC (1.5 ml l^{-1} of water) or a mixture of Monocrotophos 36SL (1.5 ml l^{-1} of water) and Dichlorvos 76 EC (1.0 ml l^{-1} of water) at an interval of 8-10 days.

4.8 Aphids (*Aphis punicae*)

Yellowish green, sap sucking insects secrete sweet mucoid substance on lower surface of the leaves which attracts the fungal growth and weaken the plant. Chlorotic patches can be seen on affected leaves. Aphids prefer high humid environment for their growth and development. Spray of dimethoate (0.03%) or monocrotophos (0.05%) or malathion (0.1%) at 15 days interval effectively controls the aphid population.

4.9 Mealy Bugs

Leaves show characteristic curling symptoms in mealy bug disease which are similar to that of a viral infection but this is caused by an insect known as *Drosicha mangiferae*. Adult female bugs are oval in shape with waxy filaments throughout the body. Sap sucking nymphs and adults secretes some droplets on fruits as their feeding activity on which black and dark brown sooty mould can grow. The severe infestation can cause fruit drop. Eggs remain torpid in the soil till the next bahar. Amid of the next following season nymphs hatch from the eggs and attack the plants. The plants in the vicinity of the orchard should be destroyed as they serve as alternate hosts for mealy bugs. Gluing an oil band of 5cm width on the main trunk stops the crawlers to climb. In contrast to the grown-ups, the crawlers are free from waxy covering; therefore crawler stage is the best stage for splashing pesticides. Spray of insecticides like dichlorvos (0.02%) or malathion (0.2%) with fish oil resin soap was found to control the insect population. Application of phorate (20 g/plant) is effective to control the pest population in the soil.

5. Disease Management

Pomegranate plant is very much susceptible towards various kinds of latent infections. Therefore, to avail maximum economic benefit from a pomegranate crop, it is desirable to protect it from the attack of various pathogens by practicing disease management. It is defined as a collection of preventive measures which are implemented for complete or partial eradication of pathogen, from a crop (Palou *et al.*, 2007). Control of disease always becomes very difficult once it spreads into the whole field. Therefore, it is recommended to follow an effective disease management program in every season to reduce the chances of both pre-harvest and post-harvest diseases. In pomegranate, it is observed that most of the infections are post-harvest but they begin in the field itself so preventive and curative measures should start before harvesting of crop (Munhuweyi *et al.*, 2016). Every disease requires a specific disease management strategy depending upon its nature (pre-harvest or post-harvest), etiology (bacterial, fungal, viral or any other pests), severity (localized or systematic) and time of occurrence etc. This section of review paper describes various strategies which are proposed and evaluated for disease management in pomegranate by different research groups.

5.1 Chemical control

This is the most common, easy to implement strategy which offers the application of synthetic chemicals (fungicides, antibiotics, insecticides or pesticides) to minimize the risk of variety of infections of pomegranate crop. Fungicides like; thiophanate methyl and tebuconazole were found to be effective against shoot blight and fruit rot (Thomidis 2015). Performance of five fungicides viz., mancozeb (0.25%), companion (0.25%), carbendazim (0.05%), copper oxychloride (0.3%) and captan (0.3%) against fruit spot and rot diseases of pomegranate was compared through field trials in India. Significant reduction in diseases was observed by the use of captan, companion and copper oxychloride, but copper oxychloride leaves scars on the fruit after spray which in turn reduces the market acceptability (Khosla *et al.*, 2008). During a survey it was found that the spray of streptocyclin (500 ppm) and copper oxychloride (2000 ppm) in a mixture was able to reduce the mean disease incidence of bacterial blight by 25.5% (Jadhav and sharma 2011). Although effective against a range of pathogenic infections, chemical methods are associated with hazardous effects on environment and human health. Continuous use of a particular chemical against a specific pest, leads to development of resistant strains (Palou *et al.,* 2007). Fungicides are normally applied as dips, fumigants, sprays, treated wraps and liners or may be mixed with fruit wax to control post-harvest pathogens and diseases thus extending shelf life of pomegranate during storage (Ghatge *et al.,* 2005). Another mechanism of chemical control by dipping of fruit in the solution of fungicides like fenhexamid and fludioxinil have been reported to decrease incidences of gray mould, caused by *B. cinerea* (Holland *et al.,* 2009).

5.2 Physical control

Implementation of physical agents like high temperature, humidity, radiation etc. comes under the category of physical control of diseases. They are more applicable for post-harvest infections and diseases in pomegranate. Temperature has proven to be effective in the form of curing, treatment with hot water, dry heating and intermittent warming. Treatment with hot water (at 45 °C for 4 minutes) was not only found to be effective to reduce chilling injury, electrolyte and potassium leakage but also improved the nutritional value of fruits. Post-harvest heat treatment leads to increase in the levels of free putrescene, spimidine and polyamines (Mirdehghan *et al.,*2007). Preconditioning or curing of pomegranate (at 30°C - 40°C and high relative humidity 90-95% for 1-4 days) improved the antioxidant activities of arils due to higher levels of total phenolics, ascorbic acid and anthocyanin. Sugar content (glucose and fructose) as well as organic acids (oxalic, citric, malic acids) also reported to be increased as compared to control (Pareek *et al.*, 2015). Among all heat conditioning (48 hrs at 35°C), intermittent warming (24 hrs at 20°Cevery 9 days) and hot water treatment (3 min, at 52°C); hot water treatment was reported to be most effective to reduce chilling injury and electrolyte leakage as well as to maintain the fruit quality (Ben Abda *et al.,* 2010). Although, it is reported that heat treatment improves the physico-chemical and nutritional qualities of fruit but temperature needs to be managed very carefully. A sudden exposure of pomegranate juice to high temperature (70°C- 90°C for 90 minutes) results into decrease in antioxidant activity, ascorbic acid and total phenolic content (Paul and Ghosh 2012) while curing and intermittent warming makes fruits susceptible to water loss. Treatment with hot water is not sufficient to control fungal growth hence it has to be supplemented either with chemical treatment or biological process for better results. Exposure of Gamma irradiation at doses higher than 2 Kilogray (kGy) caused the complete inhibition of microbial growth in pomegranate juice during storage but along with significant reduction in anthocyanin content (Wisniewski *et al.,* 2001, Alighourchi *et al.*, 2008).

5.3 Mechanical control

Proper sorting and removal of infected, diseased and damaged plants, plant parts and fruits from healthy ones comes under the category of mechanical control, which is applicable at both pre-harvest and post-harvest levels. Preparation of field before starting new plantation by removing old branches and twigs, leaves and fruits is suggested to prevent the spreading of disease to next generation. Special care must be taken after pruning as most of the plant pathogens enter into host through wounds or natural cuts. Application of protective pastes to cut ends of pruned branches has proven to be a strong strategy to restrict the infection. Although, economically not feasible but covering the fruits in bags when they are on trees is helpful to protect them from damages; caused by insects and birds (Jadhav and sharma 2011).

5.4 Biological control

Several microorganisms, plants and animals have been discovered and well known for their antagonistic effect against other living organisms. Such organisms paved the way of another stream of plant disease management i.e. biological control. It is highly recommended and considered as most sustainable approach of disease management as it has no harmful effects on environment. *Bacillus subtilis* subsp. Spizizenii (Avogreen) and *Cryptococcus albidus* (Saito) were found to be effective in controlling fungal decay of pomegranate fruit (Janisiewicz and Korsten, 2002). The biocontrol potential of several actinomycete strains had been proved against *Xanthomonas axonopodis*pv. punicae, which causes leaf spot disease in pomegranate (Chavan *et al.*,2016). The potential of various bioagents including fungi, bacteria and plant extracts have been assessed for the management of pomegranate anthracnose. Among the various microorganisms which were evaluated, the maximum decrease in PDI was obtained through *Trichoderma viride* in both *in-vitro* (79.1%) as well as *in-vivo* (18.9%) conditions. Along with that *Eucalyptus* extract showed maximum inhibition of mycelial growth of *C. gloeosporioides* (Sataraddi *et al.*, 2011). Extracts of several medicinal and ornamental plants have been analyzed by Moawad and Al-Barty (2011) for their growth retarding activity on pomegranate aphid, *Aphis punicae*. The disease control mechanisms of these biopesticides incorporate production of anti-infection agents or phytoalexins, rivalry for supplements and space with pathogenic organisms, mycoparasitism, just as incitement of host resistance (Yenjerappa *et al.*, 2013; Mutawila *et al.*, 2015).

5.5 Use of resistant cultivars

Development and subsequent cultivation of disease and pest resistant crop varieties is a strong approach for disease management. Screening and selection of existing, wild genotypes of economically important crops are prerequisites for expanding the range of resistant cultivars (Verma *et al.*, 2014; Thomidis, 2015). Limited reports are available on screening of wild genotypes of pomegranate with the aim of identification and selection of disease resistant natural cultivars. Wild genotypes of pomegranate were subjected to screening to determine their susceptibility for anthracnose disease (Jayalakshmi *et al.*, 2013), dry fruit rot and leaf spot by *Coniella granati* (Kumari and Ram 2015) and against an insect i.e. *Ectomyelois ceratoniae* (Sobhani *et al.*, 2015). A screening of total 209 pomegranate genotypes including 105 exotic types from USDA, 66 wild types and 38 cultivated types from India against bacterial blight caused by *Xanthomonas axonopodis* pv. *Punicae* was performed by Tanuja Priya *et al.*, (2016). Five genotypes showing resistance for bacterial blight (108B and 99 A from USDA and 318734, Daru-18 and IIHR.30 from India) were identified through this survey from natural pomegranate population. Increased level of defense related metabolites like total phenol, flavonoid and antioxidants were detected in resistant cultivars. Replacement of morphological markers with potent molecular markers facilitated the selection of resistant genotype from natural population. Insertion of particular gene conferring specific resistance into elite genotype became feasible through use of molecular markers and gene transfer technologies (Munhuweyi *et al.,* 2016). Thorough screening of pomegranate germplasm through advanced biotechnological tools is highly needed and will certainly assist the development of resistant cultivars.

5.6 Storage management

Post harvest storage is a critical part of disease management program. Fruits usually change their organoleptic properties (color, taste, texture, smell) and become susceptible towards variety of infections if not stored properly under recommended environmental conditions. Pomegranate fruit is very much suceptible to dehydration thus temperatre and humidity should be maintained carefully after harvesting. Although the required conditions varies according to cultivars, production areas and post harvest treatments but fruits stored at 5^oC- 10^oC at 80-95% RH remain healthy without any shrinkage or spoilage up to seven months (Caleb *et al.,* 2012; Pareek *et al.,* 2015). Spermidine and calcium chloride (Ramezanian *et al.,* 2010), polyamide plastic (Sadeghi and Akbarpour 2009), enclosing by individual film with fludioxonil (D' Aquino *et al.,* 2010) are normally embraced medications for improving the time span of usability of pomegranate by lessening the risk of weight reduction, shrinkage, rot development, appearance of physiological issue like burn and chiling damage (Elyatem and Kader 1984; Opara *et al.,* 2015). Advance and currently practiced technology for prolong storage of fruits is “Modified Atmosphere Packaging”. In this technique, fruits are packed in special, perforated bags having 5% CO_2 and 12-14% O_2 and these bags are stored at a particular temperature. Pomegranates when subjected to modified atmosphere packaging at 6^oC up to 16 weeks resulted into 7-35% reduced weight loss as compared to control (Porat *et al.,* 2006; Sachs *et al.,* 2006).

5.7 Good agricultural practices

The probability of disease incidences and pest attacks can be minimized by adopting Good Agricultural Practices. These include cleaning of field prior to next cultivation, crop rotation, intermittent cropping, management of irrigation schedule etc. Sanitation of field by removal and proper disposal of infected or dead plant parts from field decreased the PDI of anthracnose in pomegranate (Ali *et al.,* 2016; Penet *et al.,* 2016). Roberts *et al.,* (2001) suggested that crop rotation after every 2-3 years with non-host plant protects the host crop from variety of diseases while, Ripoche *et al.,* (2008) supported mixed cropping. Proper planning and implementation of irrigation program is observed to be compelling in shielding crop from broad range of infections including *Colletotrichum.* Overwatering and overhead irrigation produce adverse effects on pomegranate crop hence, advised to avoid even under drought conditions. Relatively high humidity and moisture built up under canopy favor growth of all sort of pathogens therefore, fields should have a proper drainage system (Than *et al.,* 2008).

6. CONCLUSIONS AND FUTURE PROSPECTS

Pomegranate is a most adaptable fruit crop of subtropical countries in the world. India has become the biggest producer and exporter of pomegranate during the last decade. Deccan Plateau which consists of Maharashtra, Karnataka and Andhra Pradesh states of India produces pomegranate throughout the year due to its unique geographical features and environmental conditions. Bhagwa, Ganesh, Arakta are commonly cultivated varieties of pomegranate which give huge hike to the horticulture economy. To extend the shelf life of pomegranate and to obtain a continuous fruit supply throughout the year, the physiological disorders and diseases of pomegranate should be comprehended. Pomegranates are very susceptible to various insect pests and diseases. Presently, anthracnose has become major threat to pomegranate in India causing enormous loss and has created panic among the growers. However, the pandemic nature of the disease has being studied since ages, many points are still un-researched *viz;* host-pathogen interaction, main vector for spreading the disease and most effective disease eradication strategies. It demands serious research efforts to develop high quality cultivars which have resistance to insect pests and diseases. Additionally, modifications in existing agricultural practices would be helpful in management of the disease in better way and improving the quality and quantity of the crop, subsequently giving rise to the economy of the nation.

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