Review

Flower regulation in pomegranate for higher yield, improved quality and enhanced management – a review

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Summary

Introduction – **Flower regulation is a useful approach in pomegranate to manipulate the natural flowering and fruiting in such a way that it produces higher yield with quality fruits in desired season with sustainable use of farm resources. Flower transition is a most important phenomenon in pomegranate flowering process. The differentiation of vegetative primordial to reproductive primordial determines flowering intensity and production efficiency. Pomegranate bears male, intermediate and hermaphrodite flowers on both new and old growth in one to three waves.** *Research issues* – **The pomegranate plant continues to bear flowers irregularly once, twice or thrice in a year, depending upon germplasm, agro-climatic conditions and management practices. It produces a low yield of inferior quality with non-synchronized maturity. To avoid this, flower regulation is practiced to encourage prolific harvest at specific time depending upon rainfall/irrigation facilities, pests and diseases incidence and market demand.** *Investigated research areas* – **Moisture stress, plant growth regulators, nutrient and canopy management (training, pruning and thinning) are major horticultural interventions which influence flowering. Although, many studies have been conducted in different countries to induce profuse flowering with improved sex ratio, fruit set, retention and ultimately high quality fruiting in desired season. The present review summarizes to advance induced bisexual flowers into quality fruits through horticultural interventions – deblossoming, thinning, use of plant growth regulators, micronutrients, fruit bagging, plant cover, mulching, antitranspirants, and enhanced management of physiological disorders, insect-pests and diseases and farm resources.**

Keywords
Punica granatum, deblossoming, ethrel, flower transition, sex ratio, fruit set, quality, water stress

Significance of this study

What is already known on this subject?

- Pomegranate bears male, intermediate and hermaphrodite flowers on new and old growth in one to three flushes and produces inferior quality low yield with non-synchronized maturity.

What are the new findings?

- Flower regulation induces more hermaphrodite flowers with high fruit set through moisture stress, plant growth regulators, nutrient and canopy management to encourage prolific and quality harvest at specific time.

What is the expected impact on horticulture?

- This holistic approach will encourage synchronized flowering with improved sex ratio which results in higher yield, improved quality and enhanced management of physiological disorders, pest-diseases and farm resources.

Introduction

Pomegranate (*Punica granatum* L.) is an emerging fruit crop grown in arid and semi-arid areas of India and the world. The name ''*Punica granatum*'' is derived from "*Pomum granatus*", which means "grainy apple" (Teixeira da Silva *et al.*, 2013). The genus has two species; *Punica protopunica* is a wild sour type and *Punica granatum* is a cultivated sweet type which has two sub-species, *i.e.*, *chlorocarpa* and *porphyrocarpa*. *Punica* is the only genus in the family *Punicaceae* (ITIS, 2006). The species *chlorocarpa* is found in the Transcaucasus region and *porphyrocarpa* in Central Asia (Patil *et al.*, 2002). The chromosome number varies ($n = 8, 9$; $2n = 16, 18$) in cultivars of *P. granatum* (Pross, 1938; Darlington and Wylie, 1955; Smith, 1976). The somatic chromosome number of 'Dholka', 'Ganesh', 'Kandhari', 'Muskat White' and 'Patiala' was found $2n = 16$ while the double flower cultivar has $2n = 18$ (Nath and Randhawa, 1959d). The 'Vellodu' and Kashmiri varieties have $2n = 18$ chromosome number (Raman *et al.*, 1963). A tetraploid with $2n = 32$ was obtained from 'GB-1' ($2n = 16$) by air-layering (IBPGR, 1986). Masoud *et al.* (2005) and Rana *et al.* (2010) also reported $n = 8$ chromosomes in pomegranate. *Punica protopunica*, $n = 7$, can be considered as a more primitive characteristic, while $n = 8$ in *Punica* is a factor of advancement as evolutionary perspective (Levin, 2006a).

Pomegranate is native to Central Asia, particularly Iran; owing to high adaptiveness to varied climates it spread to different geographical regions, particularly to Mediterranean region, Asia, and USA (Levin, 2006b; Verma *et al.*, 2010). The fruits, flowers, bark, rind and leaves contain bioactive compounds that are antimicrobial, reduce blood pressure, and act against serious diseases such as diabetes and cancer (Sangeetha and Jayaprakash, 2016). It has immense medicinal and nutritional value and is one of the richest sources of antioxidants (Fischer *et al.*, 2011). Owing to these medicinal and health benefits, pomegranate is known as "super food"

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(Hertog *et al*., 1997). The fruit is mainly used for dessert purposes and also processed for making juices, syrup, jelly and anardana. The dried arils of sour type pomegranate is known as anardana which is used as acidulant for making curries and chutney *etc.* Besides culinary purpose it improves mouth feel and digestion (Kingsly *et al*., 2006). Every part of pomegranate, namely root, bark, wood, sprouts, leaves, flowers, fruits, rind, and seeds have economic value (Seeram *et al*., 2006). The development of pomegranate processing industries has resulted in expansion of pomegranate areas. The pomegranate has been regarded as a food medicine of great importance for therapeutic purposes owing to its anticancer, anti-tumor, anti-proliferative and anti-inflammatory properties and its juice has shown a three-fold higher antioxidant capacity than red wine or green tea (Gil *et al*., 2000) and two-, three- and eight-fold higher capacity than those reported in grape, grapefruit and orange juices, respectively (Rosenblat and Aviram, 2006).

In the world, pomegranate is grown widely in India, Iran, China, Turkey, USA, Spain, Azerbaijan, Armenia, Afghanistan, Uzbekistan, Pakistan, Tunisia, Israel, Malaysia and tropical Africa. The global cultivated area under pomegranate is over 0.3 million ha with 3.0 million tonnes production (Sharma *et al*., 2014). India is one of the largest producers of pomegranate in the world (Jadhav and Sharma, 2007). In India, pomegranate is grown commercially in the states of Maharashtra, Gujarat, Karnataka, Andhra Pradesh, Telangana, Tamil Nadu, Madhya Pradesh and Rajasthan. During 2015–16, pomegranate was cultivated on over 0.19 million ha area with an annual production of 2.19 million tonnes and productivity of 11.39 t ha^{-1} in India (Balamohan, 2017). The area, production and export of pomegranate in India by 2025 are supposed to reach 0.75 million ha, 11.4 million tonnes and 83,800 tonnes, respectively. Masalkar *et al*. (2009) noted that the yield and quality of pomegranate fruits depend upon the flower regulation which includes selection of flowering flush, leaf shedding intensity after the rest period, pruning method and intensity, application of fertilizers and use of micronutrients, water management, control of diseases and pests *etc*. Pomegranate flowers continuously under tropical and subtropical climate and bears a small crop irregularly at different periods of the year, which may not be desirable commercially. To avoid this, flower regulation is practiced which includes withholding of irrigation for 1–2 months prior to the *bahar* to facilitate the shedding of leaves, followed by light pruning (Kumar *et al*., 2017).

India is the country where pomegranate is harvested throughout the year (January to December), particularly in states of Maharashtra and Tamil Nadu (Anon., 2014). It is considered as a saline tolerant plant due to its ability to grow well in slightly saline soils (Patil and Waghmare, 1983; Rao and Khandelwal, 2001; Asrey *et al*., 2002). The unique plasticity of pomegranate is evident from its threshold higher (44°C) and lower (-12°C) temperature limit (Westwood, 1978). It also has certain reclamation value due to its capability to thrive well on saline soils, loose sands and hilly areas (Levin, 2006a). The pomegranate growing area is increasing rapidly due to its steady demand, good keeping quality, high nutritional and medicinal value, heat and drought tolerant nature, low cost management, possibility to regulate flowering, and wider adaptability to different soils and climatic conditions. It became an imperative export oriented crop for the past decade in India due to ideal climatic conditions for quality fruit production (Chandra *et al*., 2006, 2008, 2010; Chandra and Jadhav, 2008). It is a highly remunerative fruit crop for replacing subsistence farming and alleviating poverty (Jadhav, 2007).

There is imperative need to explore information on following aspects of pomegranate cultivation for flower regulation to get high yield of quality fruits and enhanced management.

- Considering water availability – rainfall pattern, irrigation availability;
- Pest and disease incidence – bacterial blight, wilt, nematode, termite, mite *etc*.;
- Market demand – local, distance and export markets;
- Germplasm type – growth habit, flowering and maturity period;
- Agro climatic conditions – soil type, dry period, low and high temperatures;
- Water stress and chemicals effect on leaf shedding, twig sprouting, flower transition, blooming;
- Sex ratio during different season, method to increase number of bisexual flowers;
- Heterostyly, pollination, compatibility and fruit set;
- Pruning and thinning – effect on new shoot production, flower number and sex ratio;
- Plant growth and fruit quality as influenced by flower regulation practices;
- Plant growth regulators (PGRs) and micronutrients for quality improvement;
- Physiological disorders – fruit splitting, aril browning and sunscald management;
- Sustainable fruit production (orchard life).

Principles of flower regulation

The fundamental principle of flower regulation in pomegranate is to manipulate the natural flowering and fruiting in desired season that contribute to high yield of quality fruits with optimal resources utilization (Kumar *et al*., 2017). The initiation of flowering is a critical life-history trait which ensures maximal reproductive success in a given region. Initiation of flowering is due to both environmental cues and endogenous pathways (Amasino and Michaels, 2010). Control of flowering is an important adaptive trait influenced by environmental and genetic factors (Wetzstein *et al*., 2015).

It behaves as evergreen, semi deciduous or deciduous depending upon germplasm type and agro-climatic condi-

Table 1. Growth habit of pomegranate germplasm under Indian arid ecosystem.

Growth habit	Germplasm/cultivars	References
Evergreen	Jyothi, Jalore Seedless, Ganesh, Bedana Suri, P-26, Mridula, G-137, Jodhpur Red, Kabul, GKVK-1, Dholka, Coimbatore White, P-23, Yarcaud, Muskat, Patna-5, Jyoti, Bhagwa, PAU Selection and Ruby	Samadia and Pareek, 2006; Samadia, 2006; Singh, 2012
Deciduous	Bedana Thin Skin, Kurvi-2EL-24685, Speen Danedar, Basein Seedless, Kazaki Anar, Khog, A K Anar, Bocheka Lines, Gul-e-Shah, Sirin Anar, Dorsatta Malus, Tabest, Kali Sirin, Tujetis EC-10347, Nabha, Nana, Kandhari and Daru	

Table 2. Advantages and disadvantages of different *bahars* in pomegranate.

Bahars	Advantages	Disadvantages	References
Ambe bahar (February to March)	Attractive colour and good quality fruit, suitable for export. Low pest and disease incidences.	Requires assured irrigation facilities and produces low yield.	Babu, 2010; Sachin *et al*., 2015; Saroj *et al*., 2017; Sonawane, 2017
Mrig Bahar (June to July)	Does not require much irrigation and suitable for arid region.	Flowering and fruiting coincides with rainy season. Not favoured in the bacterial blight endemic area.	
Hasta bahar (September to October)	Fruits attractive with dark colored arils. Fetch high value due to limited availability.	Stress cannot be given during rainy season. Poor flowering and yield.	

tion. The growth behaviour of important germplasm/cultivars under hot arid condition of India is presented in Table 1. Pomegranate thrives best under hot dry summer and cold winter, under irrigated conditions. It flowers irregularly from February to October when watered regularly and produces low yield of inferior quality with non-synchronized maturity, which may not be advantageous commercially. To avoid this, flowering is regulated to encourage prolific harvest at specific time through a series of coordinated operations, which is collectively known as flower/crop regulation or *bahar* treatment.

The flower regulation is practiced in pomegranate according to need and choice of growers (Asrey *et al*., 2007). All the commercial varieties grown in India are susceptible to major diseases and insect pests, especially bacterial blight and wilt disease (Jadhav and Sharma, 2007). Therefore, availability of irrigation water/rainfall, climatic conditions, insect-pests and diseases, and market demand are major considerations for flower regulation. Pomegranate fruit production requires the coordination of a number of key reproductive processes, including flower development, pollination, bisexual and male flower types, fruit set, fruit attributes related to size, flower vigor, flower receptivity, and aril development (Wetzstein *et al*., 2015). Under temperate climate, pomegranate behaves as deciduous, but in sub-tropical and tropical climate it behaves as an evergreen or partially deciduous and produces flowers throughout year (Hays, 1957; Babu, 2010).

Most of the commercially grown varieties have an advantage over the others due to their free flowering nature. To harvest this beneficial characteristic, flower regulation is practiced in pomegranate, keeping in view the flowering and fruiting period of different *bahars* and their advantages and disadvantages (Table 2). Continuous uninterrupted flowering in *ambe bahar* for a long period adversely affects the overall fruit development, fruit quality, and net returns (Sharma and Singh, 2002). Chater *et al.* (2018) reported significant site and cultivar effects on many traits as well as site-cultivar interactions and 'Wonderful' was found the most productive genotype at both coastal and inland sites.

Flower biological attributes influenced by flower regulation

Selection of *bahar*/flowering season

Flowering in pomegranate occurs during spring in North India, while in Central and South India it occurs throughout the year (Singh, 1969). Sharma and Chauhan (1973) reported that in North India pomegranate produce flowers twice in a year (February–March and June–July), whereas in Central and South India thrice in a year (February, June and October). Phadnis (1974) observed that pomegranate produce flowers during spring in the cool area, while in Peninsular India, flowering occurs throughout year. *Ambe bahar* is selected in South India and Dholka area of Gujarat where enough irrigation water is available during summer (Singh *et al*., 1967; Patil *et al*., 1990). It is preferred in Maharashtra owing to better yield and quality, whereas *mrig bahar* crop is severely damaged by pests and diseases (Anon., 1981). *Mrig bahar* is selected in the North West arid region (Mann and Pareek, 1974). For getting quality fruits, January cropping is advised for Maharashtra (Sonawane and Desai, 1989), while October harvesting is suggested for Gujarat (Raturi and Hiwale, 1991). Prasad *et al.* (1997) and Singh *et al.* (2003) also reported that due to hot weather during July–August and inferior colour development and quality of fruits during January–February, both *hasta bahar* and *ambe bahar* are not recommended in arid and semi-arid climate in pomegranate.

Depending upon rainfall pattern and irrigation availability, flowering can be induced during particular *bahar*. In areas having assured rainfall (June–September) flowering in June–July is advantageous; where monsoon starts late in August, flowering during August is beneficial, the areas having assured irrigation facilities during April–May, flowering during January can be taken and where monsoon starts early and withdraws by September, induction of flowering in October is possible (Sachin *et al*., 2015; Anon., 2004). Hiwale (2009) reported that the best crop was obtained under semi-arid conditions when September flowers were advanced because fruit development coincided with maximum moisture availability and cool climate.

Hasta bahar (September–October) is not taken because withhold of irrigation is not possible during monsoon season in July–August. Flowering can be induced in pomegranate during *hasta bahar* by foliar spray of suitable growth hormones at 2–4 weeks after defoliation (Babu and Pal, 2014). In bacterial blight infected areas, *hasta bahar* should be preferred for at least 2–3 years for effective disease management. In areas having assured irrigation, *ambe bahar* is preferred. In temperate areas, February–March is the best flower regulation time so that fruits can be harvested in September–October before onset of severe winters (Anon., 2017).

Flowering habit and period

In pomegranate flowering habit is influenced by prevailing climatic condition of the habitat (Pareek and Sharma, 1993). Flowering observed throughout the year in a tropical climate, but only once a year in the sub-tropics (Stover and Mercure, 2007). In semi-tropical irrigated climate, shoot continues to grow and produce flowers even up to harvest (Ahire *et al*., 1993). Three main seasons or waves/*bahars* of flowering known as *ambe bahar*, *mrig bahar* and *hasta bahar* are reported in pomegranate (Patil and Karale, 1990; Ben-Arie *et al*., 1984; Shulman *et al*., 1984; El Sese, 1988; Assaf *et al*., 1991; Hussein *et al*., 1994; Mars, 2000). Purohit (1982)

Table 3. Flowering period of pomegranate under different climate/region of India.

Flowering period	Region	References
March to second week of May	Northern hemisphere	Singh *et al.*, 1978; Fouad *et al.*, 1979
February–March and July–August	Bihar	Ranpise *et al.*, 2014
Throughout the year	Deccan Plateau	Chandra and Meshram, 2010
Winter season	Nasik and Ahmadnagar	Marthe *et al.*, 2006
Two seasons of flowering	North India	Nalawadi *et al.*, 1973
Three seasons	Western India	Nalawadi *et al.*, 1973
Jan.–Feb., June–July and Sep.–Oct.	Central and Western India	Babu, 2010
June to August	Karnataka	Nalawadi *et al.*, 1973
April–June	Punjab	Josan *et al.*, 1979
Once or twice a year	Delhi	Nath and Randhawa, 1959
Middle of April	Himachal Pradesh	Parmar and Kaushal, 1989
February–March and July–August	Bihar	Parmar and Kaushal, 1989
March, June and October	South India	Nalawadi *et al.*, 1973; Josan *et al.*, 1979

reported that some exotic cultivars failed to produce flowers under tropical conditions of South India due to lack of temperature below 7 °C and absence of dormancy. In Israel pomegranate trees bloom from last week of April to the end of May and difference in flowering in plains and valley is owing to variation in the mean temperature (Shulman *et al.*, 1984). Chadha (1983) observed that flowers were borne terminally on previous year's growth and one to two years old spurs. Flowering was started in first week of March in the Russian cultivars and in last week of February in all Iranian cultivars at Bilaspur (Himachal Pradesh). Flowering duration ranged from 37 to 58 days.

Wild pomegranate flowers from the middle of April to end of May, although two off-season bloom of much less intensity also appear during July and November (Babu, 2010; Parmar and Kaushal, 1982; Rana *et al.*, 2003). The flowering period of pomegranate occurs about one-two month after bud-break, and varies greatly (Table 3) as it depends on agro climatic conditions, germplasm (Holland *et al.*, 2009), seasons and *bahars*. Pomegranate flowers continuously from February to October. In temperate climate it flowers only once a year during April–May, twice in North India (February–March and July–August), while in Deccan plateau of South India throughout year flowering was observed with three flushes, *i.e.*, *ambe* (January–February), *mrig* (June–July) and *hasta bahar* (September–October).

Type of flowers

Presence of different types of flowers in pomegranate was reported by many researchers (Hodgson, 1917). Evreinoff (1957) reported that hermaphrodites have well developed pistil to set fruits, while intermediate types do not set fruits and fall rapidly, but occasionally bear fruits and drop prematurely or develop incompletely. The male flowers are small with under-developed ovaries while stamens are normal with fertile pollen and fall without setting fruits. Kolesinko (1966) reported two types of flowers in Russian cultivars, *i.e.*, bell shaped, short pistillate flowers which do not form ovaries and drop down, and the other long pistillate flowers which mostly set fruits.

The pomegranate plant bears three types of flowers, pitcher-like hermaphrodite flowers, bell-shaped male, and intermediate flowers which drop early or produce misshapen fruits (Nath and Randhawa, 1959a). Nalawadi *et al.* (1973) observed that 'Dholka', 'GB-1' and local cultivars produced different types of flowers, namely male, intermediate and hermaphrodite flowers. El-Sese (1988) found perfect hermaphrodite flowers with reproductive capacity and imperfect male and intermediate flowers which cannot reproduce. The male flower is bell-shaped and has a poorly developed pistil, atrophied ovaries, infertile, and drop without fruit set. The hermaphrodite flower is vase-shaped with a normal ovary capable of developing fruit. The fruit set capacity is determined by the number of vase-shaped flowers. Therefore, cultivars with higher hermaphrodite flower to male flower ratio will have a higher fruit yield potential (Holland *et al.*, 2009).

In pomegranate, staminate, hermaphrodite and intermediate flowers develop one month after bud break on newly developed branches of same year, mostly on spur. Male flowers have rudimentary ovary, whereas intermediate have degenerative ovary and drop before maturity (Babu *et al.*, 2011). It has been observed that initially emerged flowers are male and they drop within a short period (Chandra and Meshram, 2010). Wetzstein *et al.* (2011) reported two types male and hermaphrodite flowers in pomegranate.

Heterostyly

Heterostyly was reported in pomegranate by different researchers (Babu, 2010; Sonawane, 2017; Bavale, 1978; Singh *et al.*, 2006; Karale *et al.*, 1993). Pross (1938) and Evreinoff (1957) identified three types of flowers and classified into three groups on the basis of their style length, *i.e.*, style shorter than stamen length (male), style equal to stamen length (intermediate) and style longer than stamen length (hermaphrodite). Josan *et al.* (1979) observed that in the pomegranate cultivars, heterostyly is quite common with the style length shorter than, greater than, and equal to the stamen.

Hermaphrodite or pin type flowers are usually homostylous, having stigmas on the same level or higher than the anthers, while male flowers are thrum type with stigmas beneath the level of the anthers (Babu, 2010; Ranpise *et al.*, 2014). Thrum flowers produced during *ambe bahar* were dropped (80% of total flower drop) due to presence of rudimentary ovary, whereas, pin and homostylous flower drop varied from 1.1 to 9.9% and 6.5 to 9.1%, respectively (Singh *et al.*, 2006). In pomegranate 'Ganesh' pistil length was 2.00, 1.55 and 0.65 cm in hermaphrodite, intermediate and staminate flowers, respectively (Babu *et al.*, 2011). Cizmovic *et al.* (2016) reported that hermaphroditic flowers had longer pistil (13.58 mm), while it was shortest in functionally male flower (3.93 mm). Long-styled perfect flowers are larger in size with larger ovaries, and have higher fruit set than short-style flowers, which are either functionally intermediate or male only. The ratio of these two flowers varies among cultivars and year to year (Martinez *et al*., 2000). Intermediate flowers have two styles length, *i.e*., equal to the length of the hermaphrodite flowers or as short as the male flowers. Long style intermediate flowers occasionally become fertilized, but fruit drops prematurely or becomes malformed and defective, while short-styled flowers are never fertilized and drop down in short period (Hodgson, 1917). The long-styled flowers generally develop on mature shoots, whereas the short-styled flowers appear on new growth while their ratio is influenced by many factors. The best fruit is obtained from the early bloom, probably because flowers develop during more favorable environmental conditions (Evreinoff, 1953). Male flowers have short style and abortive ovules. Only bisexual flowers with well-developed ovules are capable of setting fruit. Both male and bisexual flowers pollen were similar sized and exhibited similar germination percentage. Pollen germination is strongly influenced by temperature (Wetzstein *et al*., 2011).

Bearing habit

Pomegranate bears flowers mostly on current shoot under semi-tropical condition (Ahire *et al*., 1993). Due to heavy drop of secondary and tertiary buds, the dichasial cyme appears to be solitary in cluster (Nath and Randhawa, 1959b). Nalawadi *et al*. (1973) from Karnataka reported that flowers in pomegranate were borne on past season's growth in the axil of leaf which are mostly solitary and are rarely in cluster; terminal flowers were also observed. Singh *et al.* (1978) reported that flowers were borne on current season growth and inflorescence was observed to be cymose under Himachal Pradesh conditions. Bavale (1978) reported that in Maharashtra conditions flowers were borne on current season as well as on past season's growth either terminally or in the axil of the leaves, mostly solitary, rarely in cluster; inflorescence is dichasial cyme.

In evergreen cultivars, spring flowers are borne on old mature shoot, while summer flowers are found on current year's growth. In deciduous cultivars, flowers are borne on current growth between July and August (Babu, 2010). Pomegranate bears flowers on both old and new growth, and flowering is varying with cultivar (Reddy, 2011). Flowering occurs about one month after bud break on newly developed shoot of current year, mostly on spur or short branches, and flowers can appear solitary, in pairs or in clusters (Teixeira da Silva *et al*., 2013). The flowers are formed mostly in cluster in the axils of leaves and usually solitary when terminal (Nath and Randhawa, 1959b). The bearing habit varies with different cultivars as 'Ganesh' and 'Bassein Seedless' bear 70% flowers on the main axis and the remaining 30% on the first-order branches, whereas the proportions were almost equal in 'Orlando'. It is advantageous to have vigorous shoots with sylleptic branches, which may give about 30% flowering for the current season and contribute to 70% of flowering in the ensuing season for high yield (Venkataramudu *et al*., 2017). Pruning plays an important role in the manipulation of current and mature shoot numbers and their proportions, which bear flowers for current and ensuing season. In evergreen pomegranate cultivars, the spring flush are borne on mature wood of one-year-old shoot, whereas the flower buds which appear during summer in July–August are borne on the current year's growth (Sonawane, 2017).

Sex ratio

In different cultivars, 25–60% hermaphrodite flowers, 20–47% male flowers and 14–24% intermediate forms had been reported (Singh *et al*., 1978; Marthe *et al*., 2006; Nath and Randhawa, 1959c). The sex ratio in pomegranate depends on cultivar, blooming season, and other unknown environmental conditions. At the start of the main blooming season this percentage is higher than at the end of the season (Gur, 1986). Nalawadi *et al.* (1973) observed that local cultivar produced highest hermaphrodite flowers, 60%, and the 'Dholka' produced lowest, 38.18%. El-Sese (1988) observed highest perfect flowers in the Nab El-Gamal cultivar (35.4%) during the second year whereas the lowest was in the same cultivar in the third year (19.5%). The contribution of perfect flowers in production is very high as it has high fruit set. Bavale (1978) reported higher fruit set in perfect flowers (74.66%) as compared to intermediate (52.38%) in 'Ganesh' pomegranate and male flowers were dropped without fruit set. As far as yield is concerned, the role of hermaphrodite flower is supreme (Chaudhari and Desai, 1993). Martinez *et al.* (2000) reported that ME14 clone produces highest hermaphrodite flowers and CRO1 produces the lowest number. The PTO8 clone shows a great variability between the two years. The cultivars with higher vase to bell shape flower ratio have higher yield potential and percentage of vase-shaped flower among Israeli cultivars is 43.66% (Assaf *et al*., 1991). Nalawadi *et al.* (1973) reported 53.80% vase-shaped flower in Indian cultivars. Sex ratio depends on cultivars and reported 25 to 60% hermaphrodite flowers, 20 to 47% male flowers, and 14 to 24% intermediates in Indian cultivars (Nath and Randhawa, 1959c). Both overall flower number and the ratio of bisexual and male flowers can vary with season, plant age, position within the plant, and environment (Wetzstein *et al*., 2015).

Pollination

Self- as well as cross-pollination was observed in pomegranate. Cross-pollination is due to heterostylous nature, difference in maturity of pollen and stigma, and presence of pollinator. Gammie and Patwardhan (1929) indicated that pomegranate is a cross-pollinated crop while Pross (1938) considered it as self-pollinated crop. Nath and Randhawa (1959a) found maximum fruit set (67.72%) from hand pollination, followed by open pollination (66.15%), self-pollination (46.00%) and natural cross pollination (26.19%) in pomegranate. The fruit set in natural pollination was the highest (70.66%) in 'Sel P-23' whereas self-pollination resulted in poor fruit set (3%) in 'Sel G-137'. The increased fruit set was recorded in natural pollination and controlled cross-pollination as compared to self-pollination (Game, 1987). The stigma of the hermaphrodite is at the anthers height or emerging above them which favors self-pollination as well as pollination by insects. Wind pollination is reported to occur in pomegranate but occasionally. In hermaphrodite flowers, 6 to 20% of pollen are infertile; in male flowers, 14 to 28% are infertile. The size and fertility of the pollen vary with the cultivar and season (Morton, 1987). Emasculation and bagging studies indicated that pomegranate flowers can self-pollinate and produce normal fruit (Levin, 2006b; Mars, 2000; Nalawadi *et al*., 1973; Karale *et al*., 1993). The degree of fruit set by self-pollination varies among different pomegranate cultivars (Levin, 1978). The pomegranate is a self- and cross-pollinated plant, mainly by bees, but cross-pollination has high fruit set (Ranpise *et al*., 2014; Derin and Etis, 2001). Optimum temperature for the opening of flower buds varies with the cultivars and reported between 37 to 38 °C for 'Muskat White' (Gur, 1986). Stigmas become receptive a day before anthesis and peak receptivity coincides with time of anthesis. The stigma receptivity declines gradually and ceases altogether at the end of the third day (Nalawadi *et al.*, 1973; Nath and Randhawa, 1959a) or fifth day (Gur, 1986).

Compatibility and fruit set

A positive relation was found between the percentage of bisexual flowers and bearing capacity (El Sese, 1988; Nalawadi *et al.*, 1973; Chaudhari and Desai, 1993). The hermaphrodite flowers resulted in fruit set and fruiting; staminate flowers are meant for pollination, intermediate flowers may or may not set fruits (Ranpise *et al.*, 2014). Meena *et al.* (2011) found positive correlation between period of bud development and fruit setting. Flower size significantly affected per cent fruit set, as well as fruit size. The smallest size flowers had significantly lower fruit set (12% or 20%) as the largest size, which had over 90% fruit set (Wetzstein *et al.*, 2013). Bavale (1978) reported higher fruit set in perfect flowers (74.66%) as compared to intermediate (52.38%) in 'Ganesh' pomegranate and male flowers were dropped without fruit set. Bagging of individual flowers resulted in poor fruit set (3%) in 'Sel. G-137', indicating a certain degree of self-incompatibility. The use of genetic markers, governing the pigmentation of bud flowers and petiole base, confirmed that pomegranate is self-pollinated and cross-pollination occurs in a low proportion of 13% (Jalikop and Kumar, 1990). Sharma and Bist (2003) reported that through open pollination fruit set ranged from 9.26 to 23.32% and by self-pollination (bagging) varied from 5.91 to 13.72%, while it varied from 50% ('G-137' × 'Anar Sirin Mohammad Ali') to 90% ('Mridula' × 'Kandhari Hansi') through artificial cross-pollination. Highest fruit set was observed in crosses involving 'Ganesh', 'Ruby', 'Daru', and very low in 'Kabul Yellow' upon selfing and the same trend was observed in crosses involving 'Kabul Yellow', possibly due to poor cross and self-compatibility with other (Jayesh and Kumar, 2004). There is variability within cultivar-population; therefore, it is recommended to select the best clones in order to optimize the potential of the crop in new pomegranate orchards (Martinez *et al.*, 2006). Martinez *et al.* (2009) observed significant differences among all clones regarding pollinated flowers and fruit set was recorded 79.67% in self-pollination and 20.38% in cross-pollination (12.76% wind pollinated and 7.62% insect pollinated).

Derin and Eti (2001) stated that cross-pollination significantly influences fruit set of pomegranate. Most pomegranates are self-fertile, however fruit set has been increased 38% with cross-pollination. Some pomegranates are not self-fertile and require a compatible pollinizer (Glozer and Ferguson, 2011). The hermaphrodite flowers of 'Mridula' produced maximum viable pollens followed by 'Bhagwa' and 'Dholka', while the pollen viability of male flowers in all cultivars was significantly similar, but lower than hermaphrodite flowers (Brar, 2016). In India, 'Bhagwa' is ruling variety grown as monoculture under pomegranate which covers around 80% areas (Anon., 2016). There is good compatibility and fruit set in 'Bhagwa' under good management practices and growing of mixed clone or pollinizer cultivar is not required for compatibility. Pollen source affected fruit quality traits except aril color and taste. The best pollen source for 'Malas-e-Yazdi' was 'Bihasteh Ravar', which reduced peel thickness, but increased juice volume and TSS/TA ratio. Therefore, cultivation of at least two pomegranate cultivars in an orchard is useful to achieve more yield and better fruit quality (Vazifeshenas *et al.*, 2015). In pomegranate, pollen compatibility can affect fruit set and yield. Some cultivars had low germination percentage and in some others pollen age had most effect on pollen germination that could be considered in pomegranate growing (Vazifeshenas *et al.*, 2017).

Sonawane *et al.* (1994) reported that male flowers are unproductive and drop due to the presence of rudimentary ovary, whereas the entire fruit crop depends upon the proportion of hermaphrodite type of flowers (Singh *et al.*, 2006). The hermaphrodite flowers give a higher fruit set than the intermediate type of flowers. The fruits developed from solitary and axillary flowers are much bigger, than those developed from terminal flowers. Promoting the development of female flowers may be a means to influence yield. Fruit retention increased from about 30% during early flowering to 80% during full bloom (Hussein *et al.*, 1994). The flowers produced 4–5 weeks after flowering initiation gave the highest fruit set (90%) with best quality (Chandra *et al.*, 2010).

Both self- and cross-pollination occurs in pomegranate. Cross-pollination by hand resulted in high fruit set (67.92%) as compared to self-pollination (46.00%) in pomegranate (Nath and Randhawa, 1959b). Josan *et al.* (1979) observed that fruit set by open pollination ranged from 26.61% ('Kandhari') to 63.81% ('Dholka') and by self-pollination, fruit set varied from 20% ('Kandhari') to 53.33% ('Bedana', 'Sunni Bedana', 'Anar Malas' and 'Kazaki'). Fruit set through controlled cross-pollination was higher (76% in 'Dholka' × 'Kazki') than self- and open pollination. So it is inferred that fruit set improved by open and cross-pollination and pomegranate to be an often cross-pollinated crop. Cross compatibility study among three pomegranate cultivars exhibited that highest fruit set (48.00%) was obtained where 'Sel. P-23' was used as pollen parent and there was good cross-compatibility among the cultivars (Game, 1987). Karale *et al.* (1993) observed higher fruit set (66.2%) in artificial self-pollination as against natural self-pollination (43.3%). Fruit set through open self-pollination was 79% and it is concluded that pomegranate is capable of both self- and cross-pollination. Babu *et al.* (2011) observed 31.57% fruit set in selfing in 'Ganesh', out of which 16.66% fruits were retained after one month whereas recorded 56.66, 53.33 and 36.66% fruit set when 'Ganesh' was crossed with the pollen of hermaphrodite, intermediate and male flowers, respectively. All fruits were retained in crosses with pollen of hermaphrodite and male flowers after one month, while 50% fruit retained with pollen of intermediate flowers. Cizmovic *et al.* (2016) reported that functionally male flower had the highest number of stamens (320), which produce a sufficient amount of pollen for better fertilization, and the lowest was registered in hermaphrodite flowers (272). Open pollination was resulted in highest fruit set in 'Dholka' (63.8%), 'Bedana' (63.0%) and 'Kali Shirin' (62.7%) as compared to self-pollination which gave considerably lower fruit set (Sonawane, 2017).

Fruit cracking

Sonawane *et al.* (1994) and Pant (1976) recorded 63% fruit cracking in spring crop (January–June), 34% in winter crop (October–March) and only 9.5% in rainy season crop (July–December). Application of 0.2% boron, regular irrigation and use of mulch (Singh *et al.*, 2003) and 5% anti-transpirant pinolene (Bacha and Ibrahim, 1979) had reduced fruit cracking. Fruits are badly affected due to high solar radiation, particularly during April to June (Sonawane *et al.*, 1994). Maximum cracking and deterioration in fruits quality was reported in advanced stages of harvesting during

November–December, which might be owing to diurnal temperature variation prevailing in arid zones (Prasad *et al*., 1997; Singh *et al*., 2003). For improved colour, fruit set and fruit size, usually *mrig bahar* (June–July) is preferred in arid zones, but fruits are damaged by cracking at maturity due to day night temperature variation (Lawande, 2000). Khadivi-Khub (2015) observed that the fruit cracking varies from cultivar to cultivar under similar environmental conditions.

Methods of flower regulation

In pomegranate cultivation, flower transition is the most critical step to determine flowering intensity and production efficiency. It involves differentiation of vegetative primordial to reproductive primordial. Moisture stress, defoliants, plant growth regulators, nutrient status and canopy management (training, pruning and thinning) are major horticultural interventions which influence flowering (Saroj *et al*., 2017). In this treatment, plants are enforced to rest by withholding irrigation one to two months prior to the *bahar* followed by defoliants (ethrel) application to facilitate leaf shedding. The plants are then light pruned after water stress treatment. The recommended dose of fertilizers and light irrigation are applied. This treatment will lead to profuse flowering with improved sex ratio, high fruit set, retention, and ultimately high quality fruiting at a particular time of the year. Nevertheless, flower regulation of the crop is necessary in order to reap potential yield of quality fruits at specific gene and environment interaction. Flower regulation is performed from the third year onward and avoids putting young trees under stress. In pomegranate, flowering can be regulated by the following methods.

Stress induced flowering

The principle behind withholding irrigation is to provide rest to the plant, which results in accumulation of food in large quantity for enhancing flowering in the ensuing season. There are two methods to expose the tree against the stress; first, by water reduced stress, and second, by chemical induced stress. In the first method, 50–75% leaf defoliation is projected and considered ideal stage of stress, while in the second method 90–100% leaf defoliation is observed. Soil factors are also affecting flowering as in heavy soil 45 to 60 days water stress is given while in light sandy soil 30 days stress is sufficient. The flower induction is governed by the right quantum of water stress as a function of the combined effect of soil physico-chemical properties. To obtain higher fruit yield during a particular period, plants are exposed artificially to a resting period by withholding of water for about 60 days in advance of the normal flowering and root exposure (Sachin *et al*., 2015). In Solapur district, 45–60 days stress is given to get better quality and prolific harvest (Chandra and Meshram, 2010). Generally 40–60 days stress is imposed by withholding irrigation followed by fertilizer application and light irrigation (Chandra *et al*., 2010). Irrigation is withheld two months prior to the *bahar*, while in light sandy and shallow soils withholding of water for 4–5 weeks is required. During water stress, leaves show wilting and fall on the ground (Murthy, 2014). In pomegranate, crop regulation is achieved by withholding of water for about 30–60 days depending upon soil condition in advance of normal flowering and root exposure (Sonawane, 2017).

The water stress causes the plant to produce osmotin protein which acts as endogenous signal of flowering (Neale *et al*., 1990). Stress is used deliberately to manipulate the physiology of plant response and flowering phenomenon. Beneficial responses of stress may be uniform profuse flowering with improved sex ratio and fruit set. A positive correlation was found between leaf proline content and the number of flowers produced (Powerwanto and Inoue, 1990). Flowering is controlled by two distinct shoot initiation and inductive phases. Inductive phase determines shoot character either vegetative or reproductive. Initiation of shoot is governed by different internal and external clues than induction. The shoots which initiated during inductive, low temperature or water stress environments are reproductive shoots, whereas under normal condition vegetative shoots are produced (Southwick and Davenport, 1986). Lovatt (1990) reported that the accumulation of ammonia during stress resulted in increased biosynthesis of arginine and polyamines which subsequently increased the rate of cell division. These physiological changes and the subsequent rapid increase in cell division are pre-requisites for flower initiation. Xie *et al.* (2015) observed that water stress decreased protein concentration and increased NH_3-NH_4+, arginine and proline in leaves of pomegranate, which may induce profuse flowering.

Chemical regulation of flowering

Modifications of cultural practices, including the potential use of chemicals to promote flowering, may be ways to enhance flower production in pomegranate (Reddy, 2011; Chaudhari and Desai, 1993). Ethylene is widely used as defoliant in pomegranate for flower regulation at high concentration (2 mL L^{-1}). Ethylene activates gene expression of cell wall-degrading enzymes such as cellulase and polygalacturonase. It arrests stamen development through the induction of DNA damage, which promotes female flowers in some plant species (Wang Dong-Hui *et al*., 2010). Reddy (2011) and Pullareddy *et al.* (2011) reported that in pomegranate soil application of microbial inoculum + precursors (methionine and $FeSO_4$) resulted in higher ethylene levels in the leaves during flowering and also induced flowering on the old wood predominantly on the new growth. Spraying of KH_2PO_4 significantly increased the leaf ethylene levels during flowering which resulted in profuse flowering. Ethrel (1–3 mL L^{-1}), thiourea (5–20 g L^{-1}) or curacron (3–5 mL L^{-1}) are used for defoliation and flower induction (Chandra *et al*., 2010). Shabany and Sharif (1973) reported that ethrel 2 mL L^{-1} application caused fruit and leaf abscission. Similarly, 0.5–3 mL L^{-1} ethrel also induced flowering and fruit drop in different cultivars (Tafazoli and Badizadegan, 1972).

Ahire *et al.* (1993) observed that ethrel at 0.5 mL L^{-1} was the most effective in flower thinning and induced more hermaphrodite flowers while GA induced more male flowers and less hermaphrodite flowers in pomegranate. Chandra *et al.* (2011) reported that chemical defoliants curacron 0.4%, ethrel 0.3% and dormex 0.5% were effective for defoliation and twig sprouting in pomegranate during the winter season. Sheikh (2014) reported that defoliation of pomegranate was effective with ethrel 1 mL L^{-1} as compared to metacid 2 mL L^{-1}, profenophos 2 mL L^{-1} of water and urea phosphate 5 g L^{-1}. Murthy (2014) recommended spraying of ethrel at 2 mL L^{-1} mixed with DAP 5 g L^{-1} for leaf shedding 20 days before the start of *bahar* which improve fruit set, fruit weight, fruits number and yield per tree and induce early flowering. Supe *et al.* (2015) observed early leaf shedding by ethrel at 2 mL L^{-1}, which was statistically at par with thiourea + DAP (10 g L^{-1}) and profenophos (5 mL L^{-1}). Maximum number of female flowers (95.40), fruit set (71.00%), number of fruits per tree (94.95), average weight of fruit (263.74 g) and yield (25.05 kg $tree^{-1}$) were observed with ethrel (2 mL L^{-1}). Application of 1–2 mL L^{-1} ethephon (39%) for defoliation is recommended under Maharashtra conditions which ensures uniform flowering. More stress achieved less ethephon (0.5 mL L^{-1}) to be used for flower induction. Application of DAP 5 g L^{-1} along with ethephon gives encouraging results (Anon., 2017). In pomegranate, crop regulation was also achieved by spray of urea 10% (Sonawane, 2017).

Horticultural interventions for flower regulation

Different horticultural interventions such as plant architectural engineering, nutrient management, plant growth regulators and integrated management of pests, diseases and physiological disorders, play an important role in flower regulation in pomegranate.

Plant architectural engineering

In pomegranate, training is done during the initial 2–3 years to develop a strong framework and desirable canopy by retaining one or more main stems, while pruning is performed every year after fruit harvest by removing all criss-cross, dried and unproductive growth and light pruning during flower regulation for flower induction and making balance between vegetative and reproductive growth. In Maharashtra, growers prefer multi-stem training by retaining all stems (Sonawane, 2017). Percentage of hermaphrodite and intermediate flowers was increased while percentage of male flowers was decreased with increasing pruning intensity. The number and percentage of better grade fruit were increased in higher pruning intensity (Pawar, 1993). In pomegranate, the proleptic growth consists of vigorous, normal and spurs type shoots, where vigorous shoots were mainly confined to the main axis and spur type shoot tended to concentrate on the sylleptic branches (Reddy and Reddy, 2000). Severe pruning and retaining 40 fruit load per tree resulted in highest average fruit weight as compared to control. This treatment reduces the overall yield, but this was compensated by fetching higher prices in the market (Ustad, 2011). In pomegranate, the nature of flowering is both pleonathic and hapaxanthic, but mainly hapaxanthic (Reddy and Bhagwan, 2014). It is desirable to have vigorous shoots with sylleptic branches for effective flowering which may give about 30% flowering on the present season and contribute to 70% flowering for ensuring season, either by direct flowering on the main axis or on the first order branches (Reddy and Reddy, 2000). Pruning of old spurs is suggested to encourage new growth. Light pruning encourages growth of fresh fruit spurs, while severe pruning affects yield adversely. In bearing orchard, main (heavy) pruning performed during the winter months prior to bud break, with light pruning during flower regulation treatment. An open, vase-shaped tree with enough lateral branches is maintained which supports fruit load, ensures appropriate aeration and sunlight penetration, and reduces fruit rub on windy days.

Pruning includes removal of suckers, overcrowding branches, dead and diseased portions only. Pruning of old spurs is suggested to encourage new growth and induce flowering. Pruning of vigorous shoots by removing top one third to one fourth portion and tipping of first order branches is advocated (Reddy and Bhagwan, 2014). The pomegranate fruits are borne on spurs which bear fruits for 3 to 4 years; after that they become unproductive and need to be removed to encourage new spurs. Pruning modifies natural habits of pomegranate tree by controlling excessive vegetative growth and regulates flowering and fruiting for good quality yield. The trees are medium pruned after withholding irrigation (Murthy, 2014). Physiological factors such as photosynthesis, apical dominance, carbohydrate:nitrogen ratio and flowering behaviour are affected by pruning. Pruning alters sunlight interception, removes apical dominance, encourages lateral branching and maintains hormonal balance. The balance between vegetative and reproductive growth depends upon C:N ratio. Therefore, N application during flowering is avoided and balanced nutrition is provided. Pruning encourages more flow of nutrients and water to the flowering shoots, and improves fruit set, size and bearing. Horizontal position pruning of branches encourages flowering and inhibits vegetative growth.

Fruit thinning has pronounced effects on fruit yield and size. In favorable conditions, pomegranate plants set too many flowers and fruits which cause breaking of the branch. Therefore, thinning is carried out by removing some flowers and immature fruits in earlier stages of *bahar* to maintain optimum fruit load, which improves size and quality of fruits. Grown pomegranate tree normally produces 40–50 fruits of good size, but it can be high as 60–100 fruits per tree under intensive management practices. Sheikh (2015) reported that pomegranate plants bear flowers in abundance and excess fruit set affects fruit size and yield. Chemical thinning of flowers/fruits with ethrel spray of different concentrations caused thinning in a ratio of 1:3 to 1:5. Fruit and leaf abscission had been reported by application of 2 mL L^{-1} ethephon (Murthy, 2014). Improvement in fruit quality was observed by Raturi and Hiwale (1991) when deblossoming was carried out for obtaining a particular *bahar*. Sharma and Singh (2000) reported that juice percentage was more due to deblossoming in April compared to control in 'Ganesh' and 'Kandhari' cultivars of pomegranate.

Pruning improves number and percentage of better grade fruits, fruit size, juice content and TSS while rind and aril colour, aril content and seed hardness were not appreciably influenced by pruning treatments (Pawar *et al*., 1994). Sheikh and Rao (2002) found that severe pruning (30 cm) and retaining 30 fruit load per plant resulted in highest average fruit weight (424.28 g) which amounted to over 67% increase as compared to unpruned. Singh *et al*. (2006) reported that maximum fruit set was obtained in the trees where deblossoming was started on 7th and 15th April in 'Ganesh-1' (54.8 and 35.0%) and 'Kandhari' (35.2 and 68.3%), respectively. El-Mahdy *et al*. (2009) observed that flower thinning resulted in the highest number of grade I fruits. Flower thinning and flower thinning + spraying caused a significant decrease in grade III fruits. Day and Wilkins (2011) reported that pre-harvest summer pruning is practiced to improve fruit size, color and early harvest of pomegranate in California. This is typically accomplished by removing non-fruiting shoots and suckers from plants about 3–5 weeks before harvest. The increase in light stimulates exterior fruit color and improves photosynthetic efficiency. MacLean *et al*. (2011) suggested that pomegranates require pruning every year, and undesirable growth and suckers should be removed regularly. To get fruits of good size and quality, the flower buds in pomegranate 'Ganesh-I' and 'Kandhari' should be removed manually from 15 April and 22 April onwards, respectively, under North Indian conditions (Singh *et al*., 2011). Ghosh *et al*. (2012) found that November pruning was the best to obtain highest yield of quality marketable fruits in pomegranate under West Bengal conditions. Maximum fruit production to be harvested by 10 June, ahead of the wet season, was observed when pruning was done at the earliest date of 15 November. Chakma (2014) found maximum shoot extension, fruit retention, fruit size, fruit weight and fruit physico-chemical qualities in fruits from shoots where 15 cm fruiting shoot length is retained. However, maximum fruit set was recorded in control and it decreased with increasing pruning intensity. The pruning treatments also proved beneficial in controlling bacterial blight on fruit and leaf surface up to some extent. Fruits from trees thinned at 20 and 30% had significantly higher soluble solids; fruits from trees thinned at 30 and 40% had significantly higher TSS/titratable acidity ratio, and fruits from 40% hand thinning trees had significantly higher color hue factor (a*) than control fruit. Overall, thinning increased the commercial value and marketability of produce by increasing fruit quality and size (Jafari *et al.*, 2014).

Nutrient management

Nutrients affect pomegranate plant growth, fruit yield, quality and shelf life. Substantial amounts of macro- and micro-nutrients are being removed every year, which needs to be replenished regularly. Therefore, maintaining good soil health is important for sustainable production. The requirement of fertilizers varies as per stage of *bahar* from flowering and fruiting. Time of application varies from *bahar* as May for *mrig bahar*, October for *hasta bahar*, and January for *ambe bahar*. A five-year and above age tree requires 45 kg FYM, 625 g nitrogen, 250 g of each phosphorus and potash (Sheikh, 2006). Nitrogen metabolism regulates the induction of flower. Kato (1986) demonstrated 80% of the N utilized during the spring growth and fruit set period is derived from storage N. The timing of the normal soil application did not significantly contribute to the N requirement of the emerging flowering and vegetative flush. The regulation of flower initiation by the balance of carbohydrate to nitrogen is recognized internationally as the Kraus-Kraybill hypothesis (Goldschmidt and Golomb, 1982).

Photoperiodism and vernalization

The annual fluctuations in day length provide a reliable environmental indication regarding the time of flowering. Hence, the pathways that detect and promote flowering in response to photoperiod are among the most reliable. Knott (1934) demonstrated that inductive photoperiods are sensed by leaves. Vernalization is the process by which exposure to the cold of winter makes plants capable to produce flowers (Kim *et al.*, 2009). The passage of winter is an environmental signal that, when coupled to photoperiod sensing, provides clear seasonal information that distinguishes the spring and fall seasons. Many species require exposure to prolonged cold for breaking of bud dormancy.

Fruit quality as influenced by season, plant growth regulators and micronutrients

In pomegranate, fruit quality is influenced by season, plant growth regulators and micronutrients (Table 4). Desai *et al.* (1993) recommended spray of 250 mg L^{-1} NAA + 0.7% carbaryl after 75 days of commencement of cropping to obtain optimum yield of better grade fruit in pomegranate. Pomegranates are picked in late summer to early autumn; therefore, high temperatures exposure during summer caused sunburn damages which may exceed 30% of the harvested fruit (Melgarejo and Martinez, 1992). Singh and Kingsly (2007) reported that *mrig bahar* results in least cracking and better quality fruits with maximum juice content and TSS, desirable acidity and sugars with minimum thickness of peel. Due to hot weather during July–August and inferior colour development and quality of fruits during January–February, both *hasta bahar* and *ambe bahar* are not recommended in arid and semi-arid climates. Hiwale (2009) reported that September flowers resulted in improved quality owing to fewer incidences of insect pest and reduced cracking and fruit development coincided with maximum moisture availability and cool climate. Fruit quality attributes fruit weight, TSS, reducing sugars and sugar/acid ratio were improved when pomegranate were pruned at the earliest date in November. The colour of the aril changed with the time of maturity as it was pink during May, became light red in June, and red in July-harvested fruits (Ghosh *et al.*, 2012).

Anthocyanin content is generally lower in fruit harvested in June–July and higher in the fruit harvested in November–December. Decrease in anthocyanin content is probably due to high sunlight intensity observed during May–June. However, in some of the cultivars total anthocyanin was more in June–July than in November–December. Probably total anthocyanin content of these cultivars is not degraded even in bright sunshine (Ranpise *et al.*, 2014). In pomegranate, crop production strategies aimed at increasing aril numbers and fruit size; major problems in obtaining fruit size are reproductive issues such as poor ovule development, unsatisfactory pollination/fertilization and poor flower vigor (Wetzstein *et al.*, 2015).

Aril browning severely affects fruit quality, in which a part or all arils show discoloration and fruit become unfit for consumption (Jalikop *et al.*, 2010). Under hot arid climatic conditions, sunscald is also observed. Proper canopy development avoids the direct exposure of fruits to sunlight. Shade net and spraying of kaolin (Yazici and Kaynak, 2006; Hegazi *et al.*, 2014) and $CaCl_2$ (Bakeer, 2016) is useful in reducing the sunscald in pomegranate. Bagging the fruits with butter paper covers is useful in minimizing fruit spoilage due to sunscald. White colour bags are more effective in reflecting sunlight and protecting the growing fruits. The fruit splitting is a serious problem in pomegranate and it varies with germplasm, season, *bahar*, agro-climatic conditions and management practices. Furthermore, there is attack of insects and fungi on the cracked fruits; subsequently the fruits become unfit for marketing. Spraying with growth regulators, especially GA_3, effectively reduced the fruit splitting (Singh *et al.*, 2003; Sharifi and Sepahi, 1984; El-Kassas *et al.*, 1989; El-Masry, 1995; Mustafa, 1998; El-Khawaga, 2003, 2007; Mohamed, 2004). Boron plays a significant role in improving fruit set, retention of fruit to maturity, fruit weight, quality and yield. Boron is associated in translocation and transformation of sugars, cell division, and uptake of calcium by plant and K/Ca ratio (Zende, 1998).

Hamouda *et al.* (2016) reported that macro- and micronutrients concentration (N, K, Zn, Ca, Mg and Cu) in pomegranate fruit parts showed highly significant positive correlation with fruit yield and quality attributes such as anthocyanin and vitamin C, juice volume, fruit diameter and total sugars (Table 5).

Various good horticultural practices are becoming popular throughout the world for quality fruit production in pomegranate, such as fruit bagging, plant cover, mulching and use of antitranspirants (Table 6). Among them, fruit bagging evolved as an effective practice to improve fruit colour, internal quality and reducing blemishes; it modifies the micro-environment around fruit. Mulching and antitranspirants effectively reduce water losses from soil and plant surface, respectively. Plant covers are becoming popular in

TABLE 4. Plant growth regulators for flower regulation and quality improvement in pomegranate.

Best recommendation(s)	Positive influence(s)	Reference(s)
NAA 250 mg L^{-1} + Carbaryl 0.7%	Produced optimum cropping of better fruit grade	Desai *et al.*, 1993
NAA 10 mg L^{-1}	Increased number of bisexual flowers and numbers of fruits	Anon., 2016
NAA 40 mg L^{-1}	Improved fruit size	Anawal *et al.*, 2016
NAA 25 mg L^{-1}	High fruit set and retention with highest fruit yield; improved fruit weight and quality significantly	Ghosh *et al.*, 2009
NAA 100 mg L^{-1}	Increased number of fruits and yield	Hoang, 2003
Flower thinning + GA_3 100 mg L^{-1}	Increased grade I yield and reduced fruit splitting	El-Mahdy *et al.*, 2009
GA_3 75 mg L^{-1}	Increased plant height and spread, fruit length and diameter	Digrase *et al.*, 2016
GA_3 40 mg L^{-1}	Reduced the percentage of fruit cracking	Sepahi, 1986
GA_3 100 mg L^{-1}	Increased fruit yield	El-Akkad *et al.*, 2016
GA 50 mg L^{-1}	Increased marketable yield by improving fruit size, reducing fruit cracking and sun scald	Hegazi *et al.*, 2014
GA_3 50 mg L^{-1}	Increased fruit weight, fruit yield and reduced cracking	Korkmaz *et al.*, 2016
GA 150 mg L^{-1}	Improved fruit size	Gajarmal, 2014
GA_3 75 mg L^{-1}	Recorded highest yield in pomegranate 'Mridula'	Pawar *et al.*, 2005
GA_3 150 mg L^{-1}	Resulted in heaviest fruit with lowest fruit-splitting	Mohamed, 2004
GA 75 mg L^{-1}	Improved fruit size	Digrase *et al.*, 2016
GA_3 20 mg L^{-1}	Increased shoot length, fruit weight, aril weight, fruit acidity, reduced fruit splitting and sunburn	Attia, 2017
GA_3 20 mg L^{-1} + $CaCl_2$ 0.5% + 10% ABA	Improved vegetative growth, reduced splitting, sunburn and enhanced coloration of pomegranates	
GA_3 50 ppm + KNO_3 1%	Improved quality	Shanmugasundaram and Balakrishnamurthy, 2017
GA_3 80 mg L^{-1}	Increased fruit length, fruit diameter and total anthocyanin	Khalil and Aly, 2013
Paclobutrazol 300 mg L^{-1}	Reduced fruit cracking, increased yield and fruit quality	
NAA 40 mg L^{-1}	Significantly increased fruit length and fruit diameter	
Ethrel 0.25 mL L^{-1}	Increased hermaphrodite flowers with earliest flowering	Vidya *et al.*, 2015
Ethrel 0.5 mL L^{-1}	Most effective in thinning of flowers	Ahire *et al.*, 1993
MH 1 g L^{-1} + Carbaryl 6 g L^{-1}	Induced more hermaphrodite flowers	
Ethrel 0.2 mL L^{-1}	Improved TSS, reducing, non-reducing and total sugar; and ascorbic acid content	Goswami *et al.*, 2013
Ethrel 0.2 mL L^{-1} + NAA 25 mg L^{-1}	Increased number of hermaphrodite flowers	
Ethylene 0.2 mL L^{-1}	Reduced bacterial blight incidence, enhanced fruit yield/quality; increased phenol and anthocyanin conc.	Lalithya *et al.*, 2017
2,4-D 40 mg L^{-1} + GA 75 mg L^{-1}	Increased fruit size, aril development and yield	Reddy and Prasad, 2012
2,4-D 30, NAA 50 + NAD 100 mg L^{-1}	Improved qualitative and quantitative characters of fruits	Rahemi and Atahosseini, 2004
2,4-D 40 mg L^{-1}	Application 15 days after fruit set increased total soluble solids	Kumar *et al.*, 2016
2,4-D 40 mg L^{-1}	Increased fruit size	Reddy, 2010
2,4-D 30 mg L^{-1}	Increased fruit size	Reddy and Prasad, 2012
CCC 250 mg L^{-1}	Resulted in higher yield with maximum number of fruits per tree	Supe and Marbhal, 2014
6-BA 10 mg L^{-1}	Produced maximum fruit drop	
Epibrassinolide/Homobrassinolide 0.1 mg L^{-1}, GA_3 25 mg L^{-1}, NAA 15 mg L^{-1}	All growth regulators decreased number of bisexual flowers and increased male flowers	Engin and Gokbayrak, 2019

pomegranate due to convenient canopy, high cost of produce, improved quality and yield. It provides protection against insect-pest and disease, and frost by changing micro climate of plant.

A rest period of 3–4 months is recommended for better plant health, vigour and reduction of pathogen inoculums load. Minimum irrigation should be given during rest period. Remove the water shoots regularly.

Conclusion

Flower regulation is an effective and holistic approach for higher yield, improved quality and enhanced management. Various recommendations have been made by researchers regarding selection of *bahar* and flower regulation practices like water stress, pruning, thinning, use of different PGRs and micro nutrients, mulching, bagging, *etc*. Some researchers have recommended the *mrig bahar*, but consider-

Table 5. Macro and micro nutrients used for quality improvement in pomegranate.

Best recommendations	Positive influence(s)	References
NH_4NO_3 (1.5 kg tree^{-1}) and $CaCl_2$ (2%)	Decreased fruit cracking and sunburn; improved fruit characteristics of the 'Manfalouty' pomegranate	Bakeer, 2016
KNO_3 250 mL L^{-1}	Increased juice volume and weight	Khayyat *et al.*, 2012
K 1% and Mn 1,600 mg L^{-1}	Increased fruit yield, fruit weight and fruit dimensions	Hamouda *et al.*, 2015
$CaCl_2$ 40 or 80 mL L^{-1}	Reduced fruit cracking, improved fruit quality and yield	El-Akkad *et al.*, 2016
$CaCl_2$ 2 and 4%	Increased TSS, fruit weight and fruit yield, reduced the sunburn in the pomegranate fruits	Korkmaz *et al.*, 2016
$CaCl_2$ 2 or 4%	Improved fruit size, weight, fruit number and yield in 'Manfalouty' and 'Wonderful' pomegranate	Hegazi *et al.*, 2014
Ca $(OH)_2$ at 2%	Increased fruit length and diameter	Abou El Wafa, 2015
$CaCl_2$ 0.5 %	Increased fruit length, slightly fruit weight, aril weight, fruit acidity and reduced fruit splitting	Attia, 2017
Ca 3% + B 0.3% + Zn 0.3%	Yield and fruit weight were increased	Khalil and Aly, 2013
Urea 1% + $CaCl_2$ 2%	Highest diameter of fruit	Asghar *et al.*, 2009
H_3BO_3 0.2%	Increased ascorbic acid content	Kumar *et al.*, 2016
Boron 0.3%	Resulted in maximum fruit diameter, volume, number of fruits, fruits weight and fruit yield	Digrase *et al.*, 2016
Borax 0.2%	Minimizes fruit cracking	Sonawane, 2017
$MnSO_4$ 0.6%	Improved fruit yield, aril/peel ratio, TSS, aril weight, juice, anthocyanin, fruit diameter and leaf area	Hasani *et al.*, 2012
$ZnSO_4$ 0.3%	Increased TSS, TSS/TA ratio, juice content and leaf area	
Zn 2,000 mg L^{-1}	Resulted in highest fruit yield, fruit weight, fruit size, fruit quality-TSS, total sugars and anthocyanin	Hamouda *et al.*, 2016
Fe-EDDHA 2,000 mg L^{-1}	Increased fruit number, yield, fruit size, TSS and TSS/TA ratio of pomegranate	Davarpanah *et al.*, 2013
Zn 0.4%	Increased fruit juice dry weight, density and concentration of solid materials and minerals	Khorsandi *et al.*, 2009

Table 6. Effect of bagging, mulching and antitranspirants on fruit quality in pomegranate.

Treatment	Advantages	References
Prgmen bag	Increased fruit length, diameter, grain weight, fruit weight and yield; also increased TSS, total sugars, vitamin C and anthocyanin. Reduced cracking, sunburn mechanical damage	Abou El-Wafa, 2014
White color bag	Increased size, fruit and aril weight, antioxidant activity and reduced sun burn	Sakineh *et al.*, 2015
Kaolin 3% + green shade net 35%	Increased soluble dry matter and red color and reduced sun burn damage	Yazici and Kaynak, 2006
Bagging	Increased marketable yield by improving fruit quality, reducing fruit cracking and sun scald	Hegazi *et al.*, 2014
Kaolin 5%	Increased marketable yield by improving fruit quality, reducing fruit cracking and sun scald	Hegazi *et al.*, 2014
Black polyethylene mulch	Increased average number of fruits (58.75) and the average weight of fruits (268.75 g)	Warade *et al.*, 2009
Kaolin at 2%	Increased fruit weight and yield	Abou El-Wafa, 2015
Kaolin at 4%	Reduced cracking and sunburn; increased marketable yield and quality (TSS, TSS/acidity, vitamin C, anthocyanin, total sugars and redness of fruit)	
Red shade net 50%	Increased length of the fruit, fruit weight, and fruit yield	Meena *et al.*, 2016
Paper bag	Fruit growth in paper bag was faster and suggested for fruit bagging	Shen Dong-hu, 2009

ing insect-pest and disease issues, shifting to *ambe* or *hasta* is required for two-three year for better management. Some authors have shown advantageous results of flower and fruit thinning, but for the local market this may not be feasible. Despite cost issues, fruit bagging and plant cover have become an integral part of the commercial culture in pomegranate for improved quality and protection from insects-pest and birds. It requires series of operations, intensive care and labour. Furthermore, it is also an effective approach in reducing physiological disorders like fruit cracking, sunscald and aril browning. We conclude that flower regulation is an effective, grower-friendly technology which has several beneficial effects on the plant health, growth, yield and fruit quality. Therefore, standardization of region-specific flower regulation practices is required.

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