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Impact of temperature aberration in fruits crops: a review

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ABSTRACT

Climate change is a major threat to biodiversity, ecosystem services, and human well-being and have impact on horticultural crops, due to erratic temperature regime, rainfall, more demand for water and enhanced abiotic stresses. Changes in plant phenology are one of the earliest responses to rapid global climate change and could potentially have serious consequences for fruit crops that depend on temperature and rainfall. However, the changes will not be only harmful, as CO_2 concentration may enhance faster photosynthesis and increased temperature may hasten the process of maturity. An increasing temperature affects photosynthesis directly, causing alterations in sugars, organic acids, and flavonoids contents, firmness and antioxidant activity. Hence, there is a need to protect these valuable crops for sustainability against the climate change scenario. Temperature is a primary factor affecting the rate of plant growth and development, therefore, it influences the life cycle of fruit plants in various ways. The low temperature kills the plant tissues by freezing. Whereas, most plant tissues can be destroyed by freezing temperatures suddenly imposed during a period of growth and development. In freeze susceptible plant tissues, free water freezes forming crystals that disrupt cell membranes, whereas in freeze-resistant tissues the water is bound in the form of hydrophilic colloids. Pollination is also most sensitive phenological stages to temperature extremes. During such developmental stages, temperature extremes would greatly affect fruit production. Adverse effect of high temperature can be seen during both vegetative and reproductive growth stages in various fruit crops. The changes in gene expression that occur with cold acclimation contribute to increased freezing tolerance. The proper method of frost/freeze protection must be chosen by each crop for a particular site. Therefore, the aim of this review paper is to discuss and brought together the latest scientific information regarding climate change impact on physiology of fruit crops under varied climatic conditions.

Key words: Arid, abiotic stress, bael, aonla, karonda, temperature extremes, pollination, freezing temperature

Abiotic stresses adversely affect growth and productivity, triggering a series of morphological, physiological, biochemical and molecular changes in plants. Cold stress is a major environmental factor that limits the productivity of plants in hilly and arid region. Plants respond and adapt to cold stress to survive under stressed conditions at the molecular and cellular levels as well as at the physiological and biochemical levels. However, expression of a variety of genes is induced by different stresses in diverse plants.

Low temperature often affects plant growth and crop productivity, causing significant yield losses. Plants differ in their tolerance to chilling (0-15ºC) and freezing (<0ºC) temperatures. In general, plants from temperate climatic regions are considered to be chilling tolerant with variable degree, and can increase their freezing tolerance by being exposed to chilling, non-freezing temperatures, a process known as cold acclimation, which is associated with biochemical and physiological changes and ultimately show marked changes in gene expression, bio membrane lipid composition, and small molecule accumulation. Besides, plants of tropical and subtropical origin are sensitive to chilling stress and lack the mechanism of cold acclimation.

High temperature increase the capacity of air to absorb water vapour constantly resulting into higher demand for water. Higher evapo-transpiration indices could lower or deplete the water reservoir in soils, creating water stress in plants during dry seasons. Water stress is of great concern in fruit production, because fruit trees are not irrigated in arid and semi-arid regions in general. It is well reported that water stress not only reduces crop productivity but also tends to

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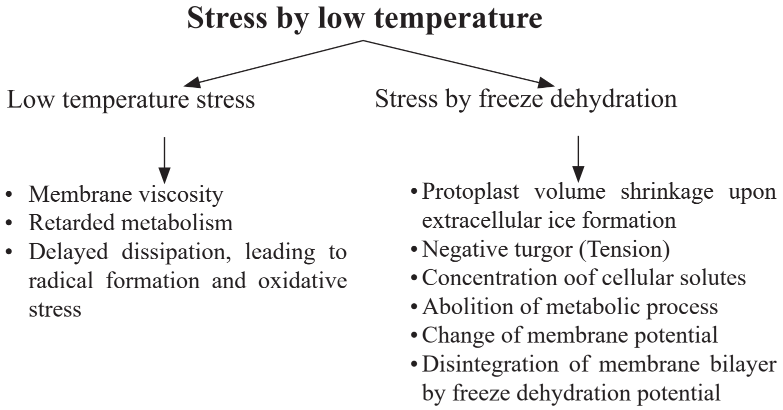

accelerate fruit ripening (Henson, 2008). During growth and development, high temperatures can affect photosynthesis, respiration, aqueous relations and membrane stability as well as levels of plant hormones, primary and secondary metabolites.

Ultimately, it causes morphological, anatomical, physiological, biochemical changes in plant tissues and as a consequence can affect growth and development of different plant organs. These events can cause drastic reductions in commercial yield. Seed germination can be reduced or even inhibited by high temperatures, depending on the species and stress level (Bewley, 1997). A general temperature effect in plants involves the ratio between photosynthesis and respiration. For a high yield, not only photosynthesis should be high but also the ratio photosynthesis/respiration should be much higher than one.

Higher than normal temperatures affect the photosynthetic process through the modulation of enzyme activity as well as the electron transport chain (Sage and Kubien, 2007). Additionally, in an indirect manner, higher temperatures can affect the photosynthetic process increasing leaf temperatures and, thus, defining the magnitude of the leaf-to-air vapor pressure difference, a key factor influencing stomatal conductance (Lloyd and Farquhar, 2008). Temperature is of paramount importance in the establishment of a harvest index. The higher the temperature during the growing season, the sooner the crop will mature. Due to rise in temperature, crops will develop more rapidly and mature earlier (Hall *et al.,* 1996). For example, citrus, grapes, melons, bael, custard apple, khirni, jamun etc. will mature earlier by about 15-30 days. High temperature and moisture stress also increase sunburn and cracking in bael, pomegranate and increase in temperature at maturity will lead to fruit cracking and burning in litchi (Kumar and Kumar, 2007)(Singh et al. 2022). Banana cultivation may suffer from high temperature, soil moisture stress or poor pollinator activity resulting in low fruit set and, ultimately, a poor crop.

Low Temperature

Low temperature (e.g. chilling and freezing) injury can occur in all plants, but the mechanisms and types of damage vary considerably. Many fruit crops of tropical origin experience physiological damage when it subjected to temperatures below about +12.5 °C. However, damage above 0°C is chilling injury rather than freezing injury (less than 0^{0}C) (Fig.1). Freezing injury occurs in all plants due to ice formation. Some exceptions are lettuce, which originated in a temperate climate, but can be damaged at temperatures near 0 °C and some subtropical fruits trees that can withstand temperatures to -5 to -8 °C.

Species or varieties show different frost damage at the same temperature and phenological stages, depending on antecedent weather conditions, and their adaptation to cold temperatures prior to a frost night is called "hardening". During cold periods, plants tend to harden against freeze injury, and they lose the hardening after a warm spell (Barua *et al.,* 2021). Hardening is most probably related to an increase in solute content of the plant tissue or decreases in ice-nucleation active (INA) bacterial concentrations during cold periods, or a combination. During warm periods, plants show growth, which reduces solute concentration, and INA bacteria concentration increases, which makes the plants less hardy (Barua *et al.,* 2021).

Morpho-physiological basis of cold tolerance

Cold tolerance involves increased chlorophyll accumulation, reduced sensitivity of photosynthesis, improved germination, pollen fertility and seed setting. Plants are damaged by freezing temperatures because the water inside the plant freezes. As liquid water is transformed into ice, it forms crystals within and between cells and tissues in plants. Ice crystals expand as they grow, taking up more space than did the liquid water. This expanding ice crushes pierces and irreparably damages, causing death of an array of critical plant tissues. This initial damage usually appears within a few days following the actual freezing temperatures but the damage observed may not represent the full extent and severity of the damage.

The inherent ability of a plant to tolerate freezing temperatures is called cold hardiness (Barua *et al.*, 2021). Cold hardiness is most often reported in terms of a specific temperature or over a range of temperatures (*e.g.,* hardy to 25º F or between 23º to 28ºF). These numbers represent temperatures at which, historically, little if any cold damage has been observed but these numbers are not a guarantee. Several factors influence cold hardiness: the maturity of plant, duration and intensity of freezing temperatures, rainfall, humidity, cloud cover vs. clear night, protection provided by other plants and structures, whether the plant is actively growing or dormant and hardened off and genetic characteristics of plants.

Many popular desert landscape trees, like hybrid mesquite (*Prosopis glandulosa* var. glandulosa), continue to grow so long as temperatures and cultural practices encourage their growth. If not hardened off succulent new wood, the result of late summer and early fall growth is especially prone to frost injury from a sudden onset of freezing temperatures. This introductory overview shows that cold, in particular frost, stresses a plant in manifold ways and that the plant's response, being injurious or adaptive, must be considered a syndrome rather than a single reaction. Syndrome is even more complex because various tissues of a plant are differently frost resistant, whereby meristematic cells are in general less frost hardy than mature tissues (Sakai and Larcher, 1987).

Another phenomenon that complicates the investigation of cold as a plant stressor is the seasonal change of frost hardiness of many perennial plants of temperate and low temperature may impose stress on a plant in a two-fold manner. The effect of low temperature alone and by dehydration of the cells and tissues when cellular water freezes, several modes of these stressors can affect a plant are shown (Fig.1). Low temperatures above the freezing point are detrimental to many plants of the tropics and subtropics which cannot acclimatize to cold. This kind of damage has been termed 'chilling' (Sakai and Larcher, 1987) and results primarily from loss of function of bio-membranes connected with a decrease of their fluidity and an inactivation or at least deceleration of the membrane-bound ion pumps.

Light energy which is absorbed independently of temperature, produces oxidative stress, if metabolism cannot keep pace with the energetization of the photosynthetic membranes. Freeze dehydration, on the other hand usually takes place at unexpectedly high extent: more than 75% of water of a frost-hardy evergreen leaf (*Pachysandra terminalis*) was frozen to ice that was deposited in intercellular spaces (Zhu and Beck, 1991). Whether, and to which extent a plant becomes damaged by exposure to low temperature depends on many factors, such as its developmental stage, the duration and severity of frost, the rates of


Sun scald in bael
Bark splitting in aonla
Burning of shoot along with fruit in aonla

Fig.1. Impact of high temperature on aonla and bael under hot semi-arid conditions

cooling (and rewarming) and whether ice formation takes place intracellularly or extracellularly in the intercellular spaces. Intracellular ice formation, by disintegration of cellular membranes, is known to be inevitably lethal.

The bilayer structure of biomembranes depends on the hydrophobic interaction with aqueous cellular phase which cannot be replaced by ice (Gordon-Kamm and Steponkus, 1994). An exception to this rule is the artificial vitrification, where upon amorphous ice is formed due to an extremely rapid cooling (10×000 K × min^{-1}) of the sample (Sakai *et al.*, 1968). Frost hardiness or sensitivity is a quality of each individual plant and is governed by its genetic potential as well as by environmental factors and therefore, usually changes with time. As mentioned above frost hardening and dehardening are accomplished by thorough changes of a tissue's cell biology.

Well known alterations affect lipid composition of biomembranes with respect to the maintenance of their fluidity (Quinn 1985; Senser and Beck 1982; Welti *et al.*, 2002; Williams, 1990), synthesis and accumulation of compatible solutes, synthesis of cold acclimation induced proteins (Close, 1997; Shinozaki and Yamaguchi-Shinozaki, 2000), changes in carbohydrate metabolism (Hansen and Beck, 1994; Hansen *et al.*, 1997; Liu *et al.*, 1998; Frankow-Lindberg, 2001) and the boosting of the radical scavenging potential of the cells (Tao *et al.*, 1998; Hernández-Nistal *et al.*, 2002; Baek and Skinner, 2003). Less studied are signals that trigger frost hardening and dehardening in evergreen perennial plants, such as conifers and even less is known plants sense such signals.

Up regulation of gene expression following exposure to cold has been reported, mainly with mono- and dicotyledonous herbs (Hughes and Dunn, 1996; Shinozaki and Yamaguchi-Shinozaki, 2000). Many studies have been performed with *Arabidopsis*, which, as an annual short-lived herb, may become frost tolerant to only some extent (Steponkus *et al.*, 1998; Takagi *et al.*, 2003). Nevertheless, it shows features of frost hardening when exposed to moderate cold and therefore, studies with *Arabidopsis* have extended our knowledge of cold hardening to level of molecular biology (Shinozaki and Yamaguchi-Shinozaki, 2000; Thomashow, 2001).Common traits between resistance to cold and to drought have been identified in particular with respect to intracellular signal transduction (Shinozaki and Yamaguchi-Shinozaki, 2000), which involves an increase of the cellular calcium level (Monroy *et al.*, 1993; Monroy and Dhindsa, 1995) and action of abscisic acid (Thomashow 1999; Ishitani *et al.*, 1997).

Freezing-tolerance mechanisms

Mechanisms responsible for freezing tolerance are not well understood.The mechanisms that could potentially contribute to freezing tolerance would include helping to prevent or reverse freeze induced denaturation of proteins, preventing molecules from precipitating, and reducing direct physical damage caused by the accumulation of intercellular ice. What is certain, however, is that cold acclimation involves the stabilization of membranes against freeze-induced damage. Indeed, whereas plasma membranes from non acclimated plants suffer expansion-induced lysis and formation of hexagonal II phase lipids upon freezing, membranes of cold-acclimated plants do not suffer from such freeze damage (Steponkus and Webb, 1992).

The stabilization of membranes against freeze-induced injury appears to involve multiple mechanisms. Steponkus *et al.* (1993) have provided evidence that the increase in membrane-freezing tolerance that occurs with cold acclimation involves changes in membrane lipid composition. Alterations that can contribute to increased freezing tolerance include increased levels of fatty acid desaturation in membrane phospholipids and changes in levels and types of membrane sterols and cerebrosides. In addition, accumulation of such and other simple sugars that typically occurs with cold acclimation seems likely to contribute to the stabilization of membranes, since these molecules can protect membranes against freeze-induced damage *in-vitro* (Anchordoguy *et al.*, 1987).There is emerging evidence that certain hydrophilic polypeptides help to stabilize membranes against freeze-induced injury.

Frost protection methods

Frost protection techniques are often separated into indirect and direct methods (Bagdonas *et al.*, 1978), or passive and active methods (Kalma *et al.*, 1992). Passive methods are those that act in preventive terms, normally for a long period of time and whose action becomes particularly beneficial when freezing conditions occur. Active methods are temporary and they are energy or labour intensive, or both. Passive methods relate to biological and ecological techniques, including practices carried out before a frost night to

Table 1: Categories and sub-categories for methods of frost protection

Category	Sub-category	Protection methods
Passive	Biological (avoidance or tolerance)	Induction of resistance to freezing without modifying plant genetics
		Treatment of the seeds with chemicals
		Plant selection and genetic improvement
		Selecting species for timing of phenological development
		Growth regulators and other chemical substances
	Ecological	Site selection for orcharding
		Modification of the landscape and microclimate
		Controlling nutritional status
		Soil management
		Cover crop (weed) control and mulches
Active	Covers and radiation	Organic materials covers without supports
		Covers with supports
	Water	Over-plant sprinklers
		Under-plant sprinklers
		Microsprinklers
		Surface irrigation
		Artificial fog
	Heaters	Solid fuel
		Liquid fuel
		Propane
	Wind machines	Horizontal
		Vertical
	Combinations	Fans and heaters
		Fans and water

reduce the potential for damage. Active methods are physically based and energy intensive. They require effort on the day preceding or during the night of the frost event. Active protection includes heaters, sprinklers and wind machines, which are used during the frost night to replace natural energy losses. A classification of methods is presented (Table 1).

Frost damage can occur in almost any location, outside of tropical zones, where temperature dips below the melting point of water (0°C). The amount of injury depends on crop's sensitivity to freezing at time of event and length of time the temperature is below the "critical damage" temperature (T_c).Fruit crops in temperate and arid climates and at high elevations have problems with frost damage.

To a large extent, the potential for frost damage depends on local conditions. Therefore, it is difficult to present a geographical assessment of potential damage. The average length of the frost-free period, which lasts from the occurrence of the last subzero temperature in the spring to the first in the autumn, is sometimes used to geographically characterize the potential for damage (Kalma *et al.,* 1992).

Frost/freeze protection

All frost/freeze protection methods are based on preventing or replacing radiant heat loss. Proper choice of protection equipment for a particular site depends on many factors. The best method of frost/freeze protection is good site selection. Microclimate monitoring may be used to evaluate a site before planting. Visualizing the flow of cold air and its possible buildup in low spots or behind cold air dams, such as fences, hedges, wooded areas, is the most effective, quick method of site selection. If a site has good cold air drainage, then it is likely a good production site as far as frost/freeze damage is concerned (Hatfield and Prueger, 2015).

Heating for protection has been relied upon for centuries. The increased cost of fuel has provided incentive to look at other methods; however, there are several advantages to using heaters that alternatives do not provide. Heaters provide protection by three mechanisms. The hot gases emitted from the top of the stack initiate convective mixing in the crop area, tapping the important warm air source above in the inversion. About 75 per cent of a heater's energy is released in this form. The remaining 25 per cent of the total energy is released by radiation from the hot metal stack. Heaters may thus provide some protection under windborne freeze conditions (Bagdonas *et al*., 1978). A relatively insignificant amount of heat is also conducted from the heater to the soil.

Heaters provide the option of delaying protection measures if the temperature unexpectedly levels off or drops more slowly than predicted. The initial installation costs are lower than those of other systems, although the expensive fuels required increase the operating costs. Growers have also tried burning old rubber tires for frost protection. Some heat is added to the crop area by these fires, but there has been a misconception that the smoke acts like a cloud. Smoke does not provide the greenhouse effect of water vapor because the smoke particles are too small to block long wave radiation loss. In fact, smoke not only has no effect on outgoing radiation, it actually impedes warming in the morning since smoke particles are the right size to block the incoming shortwave solar energy (Hatfield *et al*., 2011). Legal regulation of fires must also be considered before burning tires or other materials for frost protection.

Irrigation is another method of frost/freeze protection. Heat lost from the crop to the environment is replaced by heat released as the applied water changes to ice. Specifically, as 1g of water freezes, 80 calories of heat energy are released. As long as ice is being formed, this latent heat of fusion will provide heat. Irrigation for frost protection, often called sprinkler irrigation, is done with sprinklers mounted above or below the crop canopy. Although, there is some risk involved, the advantages of irrigation are significant. Operational costs are lower since water is much cheaper than oil or gas. Irrigation systems are convenient to operate since they are controlled at a central pump house. In addition, there are multiple uses for the same system, e.g., drought prevention, evaporative cooling, fertilizer application, and possibly pest control (Hatfield *et al*., 2011).

Wind machines capitalize on the inversion development in a radiation frost. Their purpose is to circulate the warmer air down to crop level. They are not effective in an elective freeze. A single wind machine can protect approximately ten acres, if the area is relatively flat and round. A typical wind machine is a large fan about 16 ft. in diameter mounted on a 30 ft. steel tower. The fan is powered by an industrial engine delivering 85 to 100 Hp. Wind machines use only 5 to 10 per cent of the energy per hour required by heaters. The original installation cost is quite similar to that for a pipeline heater system, making wind machines an attractive alternative to heaters for frost protection. However, they will not provide protection under windy conditions (Hatfield and Prueger, 2015). Wind machines are sometimes used in conjunction with heaters. This combination is more energy efficient than heaters alone and reduces the risks of depending solely on wind machines. When these two methods are combined, the required number of heaters per acre is reduced by about half. Helicopters have also been used as wind machines. They hover in one spot until the temperature has been increased enough and then they move to the next area. Repeated visits to the same location are usually required.

The objective of having an inexpensive material that could be stored easily until needed, easily applied and provide frost protection has existed since the mid 1950s. Numerous materials have been examined. These fall into several categories but, in general, they have been materials that allegedly either changed the freezing point of the plant tissue; reduced the ice-nucleating bacteria on the crop and thereby inhibited ice/frost formation; affected growth, *i.e.* delayed dehardening, worked by some "unknown mode of action." Yet no commercially available material has successfully withstood the scrutiny of a scientific test. Therefore, growers should be very careful about choosing these materials. Research continues and some materials have shown some positive effects. Growth regulator applications which delay bloom seem to hold the most promise at this time.

Man-made fog has been tried as a frost protection method. The principle is to duplicate the green house effect. If a "cloud" could be produced blanketing the crop area, it would decrease the radiative cooling and stop the plant from dropping to the critical temperature. So far, there has been some experimental success but a practical system has not been developed. The difficulty lies in producing droplets large enough to block the outgoing long wave radiation and keeping them in the atmosphere without losing them to evaporation.

Precautionary measures for cold injured plants

Trees that are frost damaged should not be pruned until new growth begins to appear, usually late spring or early summer of the year following the injury. Good pruning techniques should be used to prevent stimulating excessive or unwanted new shoot growth. The simplest and most effective method is to slow growth by gradually reducing irrigation and halting fertilizer application by September (Hatfield and Prueger, 2015). This will serve to reduce the amount of new, terminal (tip) growth that is the most susceptible to cold injury. Growth management of this sort can be complicated in landscapes where under-story plantings or winter and fall color plants are added at the end of the summer. Trees and shrubs planted in lawns that are over-seeded with winter grasses pose special challenges. Over-seeding requires that large amounts of water and fertilizer be applied during a season (mid to late fall) when trees being "winterized" should receive little of either. Prevention remains the most effective method of preventing cold injury. Appropriate initial landscape tree selection and proper horticultural practices keep the landscape vigorous and minimizes injury from cold temperatures.

Effect of low temperature on fruit crops

In aonla, fruits of late maturing varieties get affected by frost and low temperature (<2ºC).The fruits become whitish in colour and water starts oozing out of them and subsequently they dry and turn black. The plant growth after frost injury is adversely affecting flower/fruit production in the next crop season. Under extreme low temperature the whole plant is killed. The ber plant can survive a minimum temperature of 4 ºC and can tolerate maximum temperature of 42 ºC. The response of crop to low temperature is highly variable and cultivar specific.

It has been observed that out of 311 ber genotypes planted in National Repository of ber at CIAH, Bikaner Research farm, cvs. Tikkadi, Syriya and Sanaur showed tolerance to frost and not get affected with frost, where as cvs. Umran, Mundia and Aliganj were highly susceptible and about 50-60 per cent plants get damaged. In susceptible cultivars, the leaves, fruits and branches get affected in the outer periphery of the canopy which leads to loss of about 40 percent pruned wood weight in the crop. The cultivars Sanaur-1, Jogia and Kathapal were moderately (25-30%) affected by frost. With frost injury, the fruits get shriveled, become brown that later turns into black colour and finally dry and drop. As a result of this the yield reduction is to the level of 30 per cent in Rashmi, 20 per cent in Seb, 52 per cent in Umran, and 60 per cent in Illaichi (More and Bhargava, 2010).

Pomegranate is highly affected by the low temperature. The leaves and young shoots are severely affected by frost resulting into no flower production in next bahar. Owing to frost injury the foliage of the plant dries within 2-3 days and the plant is defoliated. The young shoots along with vital buds on the twigs dried. Initially, hardening of the fruit due to freezing and subsequently it becomes pulpy on account of thawing. The fruit finally become black due to rapid infection of pathogen. In Date palm, it was found that the crop is slightly affected by frost. It was observed that the spathe emergence, flowering and pollination are delayed if the plants experience low temperature for a longer period.

Minor increase in flower drop has been recorded and yield reduction to the tune of 10 per cent has been noticed. Prolonged low temperature also hinders the spathe emergence and flowering in male palm. Ultimately the pollination of female palms does not take place at proper time (More and Bhargava, 2010). Bael plants are relatively frost tolerant and are not affected even at low temperature of -7 ºC.The effect of frost on bael was studied and it was observed that 50 per cent of its young plantation is severely affected in the response to frost, but the plants recover speedily (More and Bhargava, 2010).

Fruits are also severely affected. Among the varieties of bael, variety Goma Yashi have more tolerance against drought than others varieties (Singh *et al*. 2019) In Kinnow, the young twigs are affected by frost and dry up and are required to be pruned for growth and development of the plant. It has been observed that after the frost,new growth in plants gets accelerated as soon as the temperature rises above 20ºC. Since the economic yield of the crop is not affected by change in the climate, particularly by the frost (More and Bhargava, 2010).

The crop has shown its potential to be an ideal for irrigation parts of hot arid and semi-arid region. Lasora is very well adopted crop of arid region. In the event of frost, lasora is first crop in the region which gets affected severely. The leaves curve and subsequently dry. Higher frost period affects young and soft twigs which finally required to be pruned. Karonda, mulberry and jamun plants are highly susceptible to frost and its young leaves and shoot get burnt (25-50%) with freezing temperature (More and Bhargava, 2010).

Effect of high temperature on fruit crops

Plant growth and development are dependent upon the temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum, and optimum. These values were summarized for a number of different crop species (Hatfield et al., 2011**)**. Temperature effects are increased by water deficits and excess soil water demonstrating that understanding the interaction of temperature and water are needed to develop more effective adaptation strategies to offset the impacts of high temperature (Hatfield and Prueger, 2015). Adverse effect of high temperature has been noted during both vegetative and reproductive growth stages in bael, jamun and aonla hot semi-arid fruit crops (Singh *et al*., 2019b 2019c and 2019d). Under rainfed semi-arid conditions of Gujarat, the fruits along with branches dried due to irradiation (Singh *et al*., 2019c) (Fig.1).

The best responses for every plant either for vegetative or reproductive growth is obtained in the cardinal temperature ranges, which includes minimum, maximum and optimum. The adverse effect of temperature on fruit plants occurs when crosses its limits. These effects are either due to direct injuries or due the reduced activity of enzymes and disturbed metabolic processes (Kumar *et al*., 2011 and Singh *et al*., 2019a). High temperature has a direct effect on physiological processes like respiration and photosynthesis. In longan and mango, with the increase in temperature from 15 to 35 ^{o}C, the photosynthesis rates increased, when the vapour pressure deficits were maintained within 1.5 k Pa. However, photosynthesis rates decreased, when the temperature increased further at the same vapour pressure deficit (Fukamachi *et al*., 1999). Limited success achieved in developing heat-tolerant fruit varieties because heat and cold tolerance in fruit setting have only moderate heritability and such inheritance is complex. Another complication is that the upper limit for fruit set can be correlated with humidity levels. Very high temperatures can limit fruit setting of arid and semi-arid fruits. In this case, intensity of insolation appears to be another limiting factor, because flowers within the leafy canopy, protected from direct exposure to sunlight, will usually set some fruit (Samedi and Cochran, 1976). A less subtle effect of extremely high temperatures on fruit set of bael is the burning or scorching (sunscald) of fruits, moisture stress along with high temperature adversely affect the flower initiation under hot semi-arid conditions of Gujarat (Singh *et al*., 2019a) (Fig1). However, fruit crops like aonla, chironji and jamun, flower bud initiation and fruit setting is adversely affected by high temperature (Singh *et al*., 2018, 2018a Singh *et al*., 2010a, 2010b 022b). Under rainfed hot semi-arid condition, bael fruits are highly affected by sun scald during April to June due to high temperature(Singh *et al*., 2011, 015 2018) Even such drastic effects, fruit along with indeterminate shoots get burnt particularly the branches located to south west direction in aonla under Godhra conditions (Singh *et al*., 2014, 2020). Navel oranges is reported to be sharply affected by temperatures during the bloom period (Davies, 1986). A high-temperature effect causing no visible symptoms is a cessation of growth even though nutrients and soil moisture are adequate, as reported for citrus trees during very hot weather (Cooper *et al*., 1964).

Flowering and fruiting are the most important events in all fruit crops which are regulated by prevailing climatic condition. Changed climatic parameters disturb the flowering pattern; fruit setting and pollination in many fruit crops like reduction pollinator activity, pollen viability (Hatfield *et al*., 2011). Rain during flowering wash out the pollen from stigma of flower resulted to poor or no fruit setting. Mango production loss 80- 90 % was reported in Gujarat due to unseasonal rain followed heavy dew attack during flowering season; which reduced fruit setting, increased fruit drop at pea stage and also increased heavy incidence of sooty mould and powdery mildew in mango. The temperature was remained detrimental to flowering to fruit setting stage. It was 33 to 36 0C during flowering stage. The flowering was reduced up to 65-70% in Saurashtra and 85-90% in South Gujarat (More and Bhargava, 2010. Barua *et al.* 2021). The quality of fruit was also going to deteriorates in test and size. In strawberry, elevated CO_2 and high temperature caused 12% and 35% decrease in fruit yield at low and high nitrogen, respectively. The less inflorescences and smaller umbel size during flower induction caused the reduction of fruit yield at elevated CO_2 and high temperature. While in custard apple, the minimum fruit retention (2.68%) recorded during the year 2008. It may be due to higher temperature, lower humidity and higher rain during June-July so; higher rain tends to more dropping of the fruit (Barua *et al.* 2021).

SUMMARY

Low and high temperature resistance in plants is a very complex trait, involving many different metabolic pathways and cell compartments. Crop plants that develop in tropical climate, often experience serious frost damage when exposed to temperature slightly below zero, whereas most crops that develop in colder climates often survive with little damage if freeze event is not too severe. The changes in gene expression that occur with cold acclimation contribute to increased freezing tolerance. The proper method of frost/freeze protection must be chosen by each crop for a particular site. To avoid damage caused by high temperature, wind breaks, use of soil moisture conservation practices, mulching etc. are useful particularly in arid and semi-arid regions.

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