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Research Review Article

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Impact of temperature aberration in fruits crops: a review

A K Singh, P P Singh[1], DS Mishra, Gngadhara K and Jagdish Rane

ICAR-CIAH-RS, Vejalpur 389 340, Panchmahals (Godhra), Gujarat, India

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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.

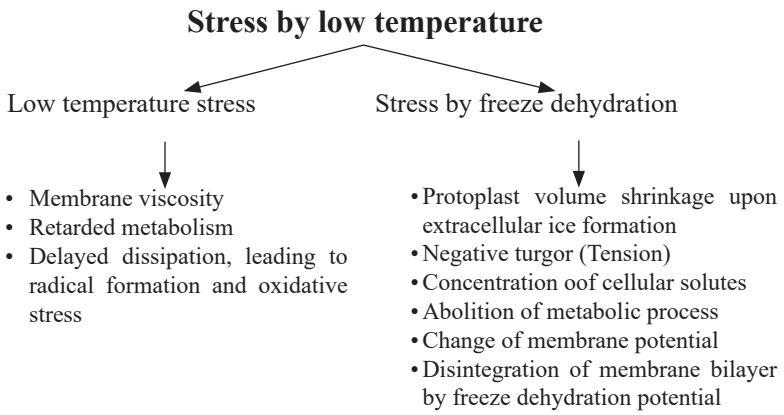
Key words: Arid, abiotic stress, bael, aonla, karonda, temperature extremes, pollination, freezing temperature

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

***Corresponding author :** aksbicar@gmail.com
[1]ICAR-IIFSR, Merrut, Uttar Pradesh



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 0^0C) (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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Hyperspectral imaging/reflectance as a tool for assessment of nutritional and quality-related parameters in tomato (*Solanum lycopersicum*) fruits - a review

Rajeev Kumar[1], Vijay Paul* and Rakesh Pandey

ICAR - Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is most important vegetable crop for human health. The postharvest handling and management of tomato is prime concern in India because the annual postharvest losses for tomato can reach up to 25 - 40 %. Non-destructive approaches for quantification and monitoring of nutritional and quality aspects of horticultural commodities have come up in a big way in the recent past that can also serves towards better postharvest management. Out of various non-destructive approaches, optical method based on visible-near infrared (Vis-NIR) spectroscopy (hyperspectral imaging and reflectance) is the most important analytical tool that provides spatial and spectral information simultaneously for a commodity towards non-destructive assessment of food quality-related parameters. Therefore, an overview with latest developments and applications of hyperspectral imaging and reflectance techniques for assessment of nutritional and quality parameters of tomato fruits have been discussed. The advantages and disadvantages of this tool along with the future perspectives are also highlighted.

Key Words: Carotenoids, Firmness, Lycopene, Maturity, Non-destructive methods, Nutritional quality, Quality assessment, Reflectance based indices, Ripeness

Tomato (*Solanum lycopersicum* L.) fruit is most important vegetable in the world with wider consumption both in raw or in processed forms (Sharma *et al*., 2022). Tomato fruit is available throughout the year and it has known beneficial effects on human health (Ali *et al*., 2021; Collins *et al*., 2022). These compounds also serve as nutraceuticals due to their anti-oxidative, anti-carcinogenic and anti-mutagenic actions. Versatile health benefits emphasize the need of tomato fruits in our daily diet (Ramesh *et, al*., 2021a; b; Collins *et al*., 2022; Sharma *et. al*., 2022). However, tomato fruit is highly perishable due to its climacteric nature of fruit ripening (Paul *et, al*., 2012; Paul *et al*., 2014). Therefore postharvest losses reach up to 25 - 40 % (Paul and Pandey, 2016; Paul and Pandey, 2018). So, to reduce

The use of non-destructive approaches are advantageous because with the destructive measurements it is not possible to monitor changes with the progress of developmental, ripening and passage of time for the same fruit or fruit lot. In this context, non-destructive measurements are of immense importance. In addition to this, identification of exact ripening stage and quality status in a non-destructive way can also provide more reliable and meaningful information on fruit biology, fruit physiology and fruit ripening that in turn become key in deciding the time of harvesting, need for grading, transportability, potential shelf-life, overall storability and final quality aspects (Dale *et, al*., 2013; Tiwari *et al*., 2013; Paul *et, al*., 2018; Wang *et al*., 2021). Furthermore, dynamics of bioactive compounds present in fruit is also strongly related to progression of ripening and changes in physiological status. Changes in profile of bioactive compounds over a period of time can also form an applied perspective to a wide range of scientific investigations with practical applicability for physiological processes such as fruit ripening and ripening-related changes (Paul *et, al*., 2011; Sharma *et, al*., 2020).

Non-destructive methods with above merits will be highly desirable for monitoring, remote, online, mechanization and automation of handling, sorting, quality assessment and packaging of fresh commodities in economic, safe and environment-friendly way (Hussain *et al*., 2018; Wang *et al*., 2021). Various aspects related with supply chain of tomato including quality control, inspection, random sampling, selection, decision making and exportability can also get facilitated with the availability of such techniques/methods (Jiang *et al*., 2013; Wu and Sun 2013; Paul *et. al*., 2018). Out

***Corresponding author :** vijay_paul_iari@yahoo.com

[1]ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

of various non-destructive methods, optical method based on visible-near infrared (Vis-NIR) spectroscopy (hyperspectral imaging and reflectance) is emerging as the most important analytical tool for assessment of food quality. This technique has been employed for estimation of various quality and other physiological parameters in a number of fruits and vegetables (Jha and Garg, 2010; Xiang *et al*., 2022; Hasanzadeh *et al*., 2022). This review presents an update on developments and applications of hyperspectral imaging/reflectance technique for the assessment of nutritional and quality parameters of tomato fruits. It also presents advantages and disadvantages of this technique along with the future perspectives.

Hyperspectral imaging and reflectance

All food samples continuously emit and absorb energy by lowering or raising their molecular energy levels when exposed to light or in presence of light. The wavelengths at which molecules absorb, reflect, and transmit electromagnetic radiations revel the characteristics of their structure and composition (Sun, 2010). Any biological material and food tissues are held together by several different molecular bonds and forces. Water, carbohydrates and fats are rich in O-H or C-H bonds. Organic compounds and their derivatives are rich in C-H or N-H bonds. When a food sample is exposed to light, electromagnetic waves are transmitted through it, the energy of incident electromagnetic waves [ranging from ultraviolet radiation (UV), visible light (Vis), near-infrared (NIR), mid-infrared (MIR) and far-infrared (FIR)] change because of the stretching and bending vibrations of chemical bonds such as O-H, N-H and C-H (Wang *et al*., 2021). The changes in molecular energy levels are able to tell *via* spectroscopy about the characteristic and detailed fingerprints of food samples. At the macro level, the electromagnetic waves are recorded as light and the transitioning of the incident electromagnetic waves emerge out as reflection, scattering, and transmission of light. Since the absorbed part of light penetrates into the tissue of samples, the strength and wavelengths of emission and absorption depend on the physical and chemical states of the objective material. The emerging light can be converted into a spectrum and reshaped into images by hyperspectrometers with high signal to noise ratios. The obtained images (hyperspectral images) and reflectance (hyperspectral reflectance) indicate the chemical constituents and physical properties of the food samples.

Hyperspectral imaging or reflectance, also known as chemical or spectroscopic imaging or reflectance, are the most powerful and fastest-growing non-destructive tools for food quality analysis and control (ElMasry and Sun, 2010; Wu and Sun, 2013). They integrate imaging and spectroscopy technologies into one system that provide both spatial and spectral information simultaneously from an object (commodity). Thus, hyperspectral imaging and reflectance has capability to monitor rapidly and non-invasively both, physical and morpho-physiological characteristics besides the intrinsic chemical and molecular information of a food product for the purpose of quality assessment and safety analysis. Thus, hyperspectral imaging/reflectance is a very powerful technique for characterizing and analyzing biological and food samples. Keeping in view of various merits and large number of applications of this technique, there has been an increasing interest in hyperspectral data acquisition with a focus to develop techniques/methods for analyzing spectra of plant part to quantify and then predict the concentrations of pigments, contents and physiological status of plant part under investigation.

Acquisition of hyperspectral data

There are three common sensing modes for hyperspectral imaging, namely; reflectance, transmittance and interactance as illustrated in Fig. 1 Positions of light source and the optical detector (cameral, spectrograph, and lens) are different for each of the acquisition mode.

Reflectance mode: Detector capture the reflected light from the illuminated sample in a specific conformation to avoid specular reflection (Fig. 1a). External quality features can be detected using reflectance model which include size, shape, colour, surface texture and external defects etc. Reflectance mode can be used for thicker samples. It is therefore that food materials can be inspected as a whole in reflectance mode without the need to make slices.

***Transmittance mode*:** Here detector is located in the opposite side of the light source (Fig. 1b), it captures the transmitted light through the sample which carries more valuable internal information but it is often very weak. Transmittance mode is usually used to determine internal component concentration and internal defects of relative transparent materials such as; fruit, and vegetables. Transmittance mode has a low signal level from light attenuation and

is affected by the thickness of the sample. So, to acquire images in transmittance mode, sample size should be thin that allows the light to travel through the sample.

***Interactance mode*:** Both the light source and the detector are located in the same side of sample and parallel to each other (Fig. 1c). On the basis of such setup, the interactance mode can detect deeper information from the sample and has less surface effects compared to the reflectance mode. Interactance mode reduces the influence of thickness and this has practical advantage over the transmission mode. There is a need of special setup in the transmittance mode to seal the light in order to prevent specular reflection from directly entering to the detector.

Distinctive pattern of reflection, absorbance, transmittance and/or emitting of electromagnetic energy from different materials due to difference in their chemical composition and inherent physical structure at specific wavelength is referred as spectral signature. Hyperspectral measurements are not only surface based phenomenon. Most food products have very strong absorption of light, making them opaque over a distance of about several millimetre in visible and NIR regions. Lammertyn *et al.* (2000) calculated the light penetration depths in apple fruit. The depth was up to 4 mm in wavelength range of 700 to 900 nm. In other study, Hampton *et al.* (2003) reported that maximum penetration depth in mid-infrared region is usually a few micro meters and this is shorter than that of NIR region. The ratio of light reflected from a surface patch is often referred to as the bidirectional reflectance distribution function (BRDF) and it is a function of directions of incoming and outgoing light. The BRDF depends on the properties of the object. Material properties vary from perfect diffuse reflection in all directions (Lambertian surface) and specular reflection mirrored along the surface besides the dependency on wavelength. So, in general, diffuse reflectance is responsible for the colour of the product. More the cells involved in reflectance, the more useful will be the chemometric information obtained in the form of reflectance spectra. Basic physical aspects of light falling on surface such as tomato fruit are illustrated in Fig. 2.

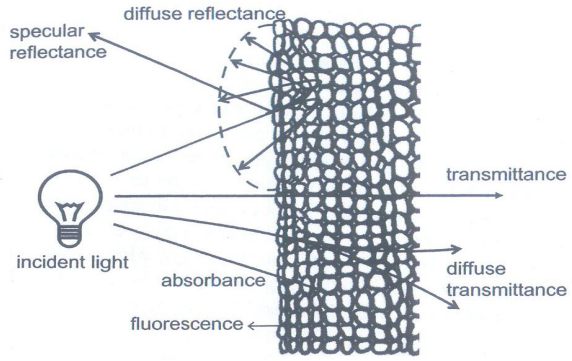
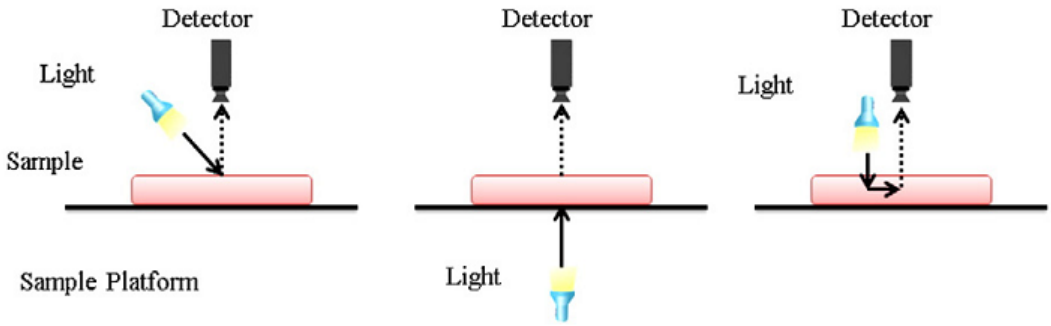


Fig. 2: Incident light on the tissue of tomato fruit results in specular reflectance, diffuse reflectance, transmittance, diffused transmittance, absorbance and fluorescence. All these physical parameters are dependent on external (surface features, colour) and internal (chemical constituents, texture) aspects of tomato fruit besides the wavelength of the light. *Source*: Polder and van der Heijden (2010).

Hyperspectral imaging/reflectance for quality analysis

In the past two decades, hyperspectral imaging has been explored intensively for analysing physical, chemical and biological properties of a broad range of food and agricultural products for quality and



(a) Reflectance (b) Transmittance (c) Interactance

Fig. 1: Acquisition approaches of hyperspectral imaging. *Source*: Wu and Sun (2013).

safety aspects from a macroscopic approach to a more limited field area. Vis-NIR range is used to measure food quality (particularly fruit quality), determining the internal constituents of food products, online detection of diseases and chemical, microbial or biological contaminants (Gomez-Sanchis *et al*., 2012), impurity discrimination (straw, broken grains, grains from other crops, weed seeds, insects, plastic, stones, pieces of wood and paintings, animal feces) in many cereals such as wheat, spelt and barley (Fernandez Pierna *et al*., 2012; Hussain *et al*., 2019), maturity determination (Menesatti *et al*., 2008), discrimination of botanical families and plant species and also for detection of toxic and invasive plants from mixed meadows (Dale *et al*., 2011; Punalekar *et al*., 2016). Hyperspectral imaging has been used widely for evaluation of internal starch, total soluble solids, titratable acidity, water content, acidity, sugars, pH, oil content, pigments, dry matter content, stiffness, physiological defects, physiological disorders and other properties of fruits and vegetables (Magwaza *et al*., 2014; Paul *et al*., 2018).

A typical reflectance pattern of a tomato fruit at three different ripening stages is presented in **Fig. 3**. Distinct differences in the reflectance pattern are due to the ripening stages or degree of maturity of tomato fruit (Kumar *et al*., 2022a). Typical characteristics of reflectance spectra of tomato fruit as described by Sun (2010) and Szuvandzsiev *et al.* (2014) are as follows: 1) Intense absorption at 560 nm, 2) Above 560 nm, reflectance values become higher, 3) Maximum reflectance can be recorded between 645 and 713 nm, depending on the sample, 4) Green fruits show a valley near 670 nm which is due to absorption by chlorophylls, 5) With the progress of ripening chlorophyll valley disappear and an absorption valley is formed in 400-550 nm and 6) A local absorption maximum at around 980 nm is seen in near-infrared (NIR) region and this is due to the presence of carotenoids.

The hyperspectral imaging/reflectance technology has been applied in various fields related to tomato including grading, processing, and marketing etc. The power and potential of this technology can be judged from the fact that Vis-NIR diffuse reflectance spectroscopy combined with multivariate analysis was successfully used to differentiate 70 transgenic tomatoes and 94 of their parents (Xie *et al.,* 2007). This was also employed for non-destructive determination of internal defect (Cho *et al.,* 2013), ripeness (Polder and van der Heijden, 2010), maturity/physiological maturity and internal chemical attributes (moisture, soluble solids, pH, lycopene, β-carotene, polyphenols and firmness) of tomato fruits (Van de Poel *et al.,* 2012; Tiwari *et al.,* 2013; Rahman *et al*., 2017; Huang *et al*., 2018; Alenazi *et al*., 2020; Zhao *et al*., 2022). A detailed compilation of the work done in last two decades on non-destructive assessment of different nutritional and quality parameters in tomato fruits by hyperspectral imaging/reflectance has been presented in Table 1.

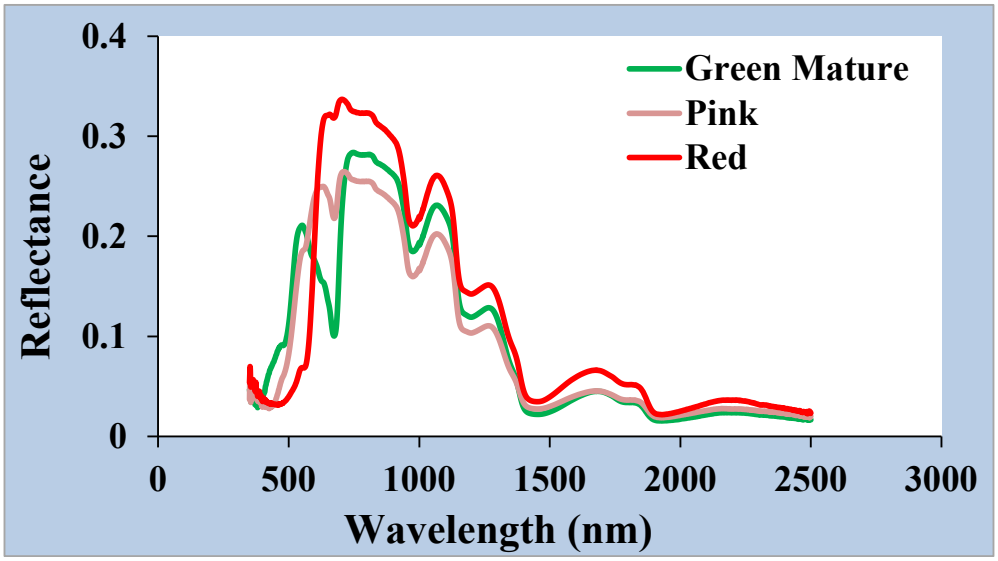


Fig. 3: Reflectance spectra of tomato fruit at three different ripening stages. *Source*: Kumar *et al.* (2022a)

Table 1: The work as done during last two decades on non-destructive assessment of different nutritional and quality parameters in tomato fruits by hyperspectral imaging/reflectance

Parameter	Wavelength range (nm)	References
Moisture content	1000-1550	Rahman *et al*. (2017)
Soluble solid content	1000-1550	Rahman *et al*. (2017)
Soluble solid content	550-1650	Huang *et al*. (2018)
Soluble solid content	650-930	Egei *et al*. (2022)
Soluble solid content	400-1000	Xiang *et al*. (2022)
pH	1000-1550	Rahman *et al*. (2017)
pH	550-1650	Huang *et al*. (2018)
pH	400-1000	Xiang *et al*. (2022)
Sweetness index	1000-1550	Rahman *et al.* (2018)
Maturity/ripeness	530, 595,630 and 850	Hahn (2002)
Maturity/ripeness	396-736	Polder *et al*. (2002)
Colour	600-1100	Kusumiyati *et al*. (2008)
Colour	430-1400	Chen (2008)
Colour (*L**, *a**, *b**, Hue, chroma)	325-985	Van Roy *et al*. (2017)
Chlorophyll *a* and *b*	450-600	Chen (2008)
Lycopene	400-600, 600-800, 800-1000, 400-1000	Pedro and Ferreira (2005)
Lycopene	450-1000	Chen (2008)
Lycopene (ripening on and off the plant)	623-1052	Kusumiyati *et al*. (2008)
Lycopene	380-950	Berra (2012)
Lycopene	550-975	Szuvandzsiev *et al*. (2014)
Lycopene	370-1040	Saad *et al*. (2014)
Lycopene	360-750, 400-1000, 450-1150	Clement *et al*. (2015)
Lycopene	950-1650	Deal *et al*. (2015)
Lycopene	500-1100	Tilahun *et al*. (2018)
Lycopene	950-1650	Ibrahim *et al*. (2018)
Lycopene	400-700	Alsina *et al*. (2019)
Lycopene	285-1200	Alenazi *et al.* (2020)
Lycopene	590-790	Saad *et al.* (2021)
Lycopene	650-930	Egei *et al*., (2022)
β-Carotene	400-600, 600-800, 800-1000, 400-1000	Pedro and Ferreira (2005)
β-Carotene	500-1100	Tilahun *et al*. (2018)
β-Carotene	950-1650	Ibrahim *et al*. (2018)
β-Carotene	400-700	Alsina et al. (2019)
β-Carotene	285-1200	Alenazi *et al.* (2020)
Polyphenols	550-975	Szuvandzsiv *et al*. (2014)
Total phenolics	285-1200	Alenazi *et al.* (2020)
Total flavonoid	285-1200	Alenazi *et al.* (2020)
Firmness	500-1100	Chen (2008)
Firmness	1100-1800	Sirisomboon *et al*. (2012)
Firmness (on and off the plant)	623-1052	Kusumiyati *et al.* (2008)
Firmness	350-2500	Ecarnot *et al*. (2013)
Firmness	716, 1000	Elsayed and Ghazy (2017)
Firmness	1000-1550	Rahman *et al.* (2018)
Firmness	285-1200	Alenazi *et al.* (2020)
Firmness	400-1000	Xiang *et al*. (2022)

Recent reports, with the use of reflectance at one or two wavelength/s, have shown that out of whole range of hyperspectral spectrum; specific wavelength/s (that too in the visible range) are also effective in prediction of various ripening and quality related parameters of tomato fruits. The indices identified and models developed were found to be valid across the fruits of tomato varieties and hybrids and equally good for harvested and stored tomato fruits as well. Index based on the reflectance value at wavelength 521 nm i.e., R_{521} yielded the best prediction model for non-destructive estimation of colour, ripeness or maturity of tomato fruit. For this, model [y (colour/ripeness/maturity score) = - 2.456 ln (x) - 1.093 where x is reflectance at 521 nm (R_{521})] with values of $R^2 = 0.80$, SEP = 0.87, RMSEP = 0.86 and bias = 0.09 indicated the potentiality to distinguish at least basic or standard ripening stages of tomato fruit from one another (Kumar *et al*., 2022a).

Likewise, the model for lycopene content i.e., y [μg g^{-1} fresh weight (FW)] = 0.1713x - 1.789 where x is R_{546} was identified as the best model for prediction of lycopene content up to a difference of ≥ 5.04 with biasness of 0.10 (Kumar *et al*., 2022b). In addition, the model for firmness [y (N) = 1260.800 x + 3.309] based on the index i.e., x = R_{501} (1^{st} derivative) was the best for prediction of firmness of tomato fruits and this model can predict the firmness for a difference of ≥ 1.05 N with biasness of − 0.01 N (Kumar *et al*., 2022c). For total carotenoids in tomato fruits, model y (μg g^{-1} FW) = 1.6638 $x^{-1.353}$, wherein x is R_{582} emerged out as the best model with values of 8.78, 7.65 and - 0.12 for RMSEC, RMSEP and biasness, respectively (Kumar *et al*., 2022d). In all the above studies, developed models can be considered as simple and rapid because they are based on reflectance at single wavelength and that too in the visible range.

Advantages and disadvantages of hyperspectral imaging/reflectance

Various advantages and disadvantages of hyperspectral imaging/reflectance are as follows:

Advantages

- It is a novel technique that obtains both spatial and spectral information of an object (sample).
- It requires minimal or no sample preparation.
- It is chemical-free assessment which enables safety and environmental protection.
- It is non-invasive, so the sample could be used for time series or other purposes analysis.
- It is economical compared with traditional methods because it saves labour, time, reagent cost and other costs.
- Rather than collecting a single spectrum at one spot on a sample (as in spectroscopy) hyperspectral imaging records a spectral volume that contains a complete spectrum for every spot (pixels) in the sample.
- It has flexibility in choosing any region of interest (ROI) within the image even after image acquisition. Also, when an object or a ROI in the object presents very obvious spectral characteristics, that region could be considered as a spectral signature and it can be saved in a spectral library.
- Hyperspectral images are reasonably independent of light source.
- Due to high spectral resolution, hyperspectral imaging provides both qualitative and quantitative measurements.
- Able to determine several constituents simultaneously in the same sample.
- Able to delineate multiple distribution of different constituents within a sample, not just the bulk composition.
- Competent in detection and discriminate of different objects even if they have similar colour, overlapped spectra or morphological characteristics.
- It allows identification of different biochemical constituents presented in a sample based on their spectral signatures because regions of similar spectral properties have similar chemical composition. This process is called as building chemical images or chemical mapping (required for constructing detailed maps of the surface composition of foods) which otherwise/ traditionally requires use of intense laboratory methods.
- Potential to detect even the diseases and defects in agricultural products and food items.
- As of today, with the use of appropriate tools available in the form of different software and statistical methods, it is possible to characterize the main sources of spectral variability and to pin point the optimum wavelength/wavebands that offer maximum information or content related information.

There are however some constrains in this hyperspectral imaging/reflectance and they are as follows:

Disadvantages

- It contains much redundant data that pose considerable challenges for data mining.
- It takes a long time for image acquisition and analysis, so pose difficulty in direct implementation in online application or automated quality evaluation.
- Slow computation speed, limitations of hardware and high cost are the major factor that limits its use. In fact, there is requirement of high speed of hardware for rapid image acquisition and analysis of huge amount of data.
- Hyperspectral data suffer from well-known problem of multicollinearity. Some multivariate analysis techniques like principal component regression (PCR) and partial least square (PLS) are often employed to overcome this problem. The effects of multicollinearity in data can only be reduced but cannot be completely removed by PCR and PLS.
- Not suitable for analysis of liquids or homogenous samples, because the value of imaging lies in the ability to visualize spatial heterogeneities in samples.
- Not suitable when the region of interest (ROI), within the surface of a sample, is smaller than a pixel or the quality attributes have no characteristic spectral absorption.
- Being indirect method, needs standardization calibration and model transfer procedures.
- Modeling and data processing is time consuming; interpretation programs are very expensive and specialists are needed for calibration and standardization.
- Potential heating effect is found in the measured hyperspectral images of food, due to presence of water.
- Cannot detect the information of constituents very deep inside the food samples.

FUTURE PERSPECTIVES

In the last two decade a great progress has been made in use of hyperspectral imaging/reflectance for the assessment of nutritional quality of tomatoes. However, still lots need to be done towards the transfer of this technique from the laboratories to the end users at small, medium and industry levels. Presently, the main limitation includes the high cost of the instrument/s. Since, most of the developed models were based on wavelength range and this increases the manufacturing and operational cost of the instrument. So, further work can also focus on assessment of nutritional and quality parameters of tomato by using a single or at the most two different wavelengths (preferably in vis-NIR region).

This will help in reducing the cost of the instrument with possibility of usage even up to the farmer's level. In the near future, identified indices and the developed models can be translated into cost-effective tools/ technique with wider applicability covering not only the basic research (rapid or automated phenotyping, screening, monitoring and sorting of tomato fruits) as desired by breeders, physiologist, horticulturist, food scientists and but also the applied fields (automated colour or quality based grading of tomato fruits) as desired for better postharvest management and by marketing, processing, agri-industry value-addition and pharmaceutical sectors.

Survey of previous and recent literature indicate that future work on hyperspectral imaging/ reflectance for quality assessment need to give more emphasis on the following aspects:

- To actually realize the full potential of hyperspectral imaging/reflectance as a non-destructive analytical tool for quality and physiological status determination.
- Making use of NIR region for assessment of quality parameters and plant constituents.
- Multispectral imaging should aim for acquiring the spectral images only at several optimal wavelengths to meet the speed requirement of quality assessment and inspection. Such optimized multispectral imaging systems have much lower dimensionality than the hyperspectral imaging system, resulting in taking less time in data acquisition.
- Using the above approach of multispectral imaging and thereby developing indices/models based on wave band/s or wavelength/s selection. This can give better result than the use of full or part of spectrum.
- Increasing the efficiency/robustness by identification of key/contributing wave bands or wavelengths that can give minimum error with maximum discrimination power/quantification ability.
- There is still need for improvement in interpretation of acquired data by making use/ developing suitable statistical technique in the

process of chemometric analysis which is a key component of index/model development.

- Minimization of errors by taking more varieties, number of samples from different locations and over different years of harvest.

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Precision viticulture: a review

R G Somkuwar and Sharmistha Naik

ICAR-National Research Centre for Grapes, P.B. No. 3, P.O. Manjari Farm, Solapur Road, Pune 412 307, Maharashtra, India

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ABSTRACT

The precision viticulture aims to optimize grape (*Vitis* spp. L.) vineyard management; reducing use of resources and environmental impacts; and maximizing quality yield. New technologies as UAVs, satellites, proximal sensors, variable rate machines (VRT) and robots are being developed and used more frequently in some parts of the world in recent years. Developments and abilities of computers, software and informatic systems to read, analyze, process and transfer a huge amount of data are major milestones in precision viticulture. In addition, different decision support systems (DSSs) for making better crop management decisions at the right time also assist vine growers. In the fragmented small vineyards in India, relatively cheaper technologies like UAV, proximal monitoring through various tools, and DSSs developed by the ICAR-NRC for Grapes, Pune, Maharashtra, India can be used by individual grape grower or through farmers' cooperatives/groups to make grape cultivation technologically-, economically- and environmentally- viable. Therefore, current status of precision viticulture technologies and their potential applications in viticulture, have been discussed.

Key words: Remote sensing, Proximal sensing, Variable-rate technology, Robots, Decision support system, Vineyard

Grape (*Vitis* spp. L.), most important fruit crop in the world, is grown in a wide range of environments (Somkuwar and Ghule, 2020). Total world grape production in 2020 was 78.03 million t from an area of 6.950 million ha (FAOSTAT, 2022). In India, grape is cultivated in almost all parts having diverse climatic conditions ranging from extreme temperate regions of Himachal Pradesh to tropical parts of South India. As per the 3rd advance estimate, India produced 2.94 million t of grapes from an area of 0.147 million ha in 2019-2020 (DA&FW, 2022). Grape is a high input crop needing application of several expensive inputs including repeated use of pesticides.

As such cost of grape production is more and indiscriminate use of inputs leads to food safety issues and environmental degradation. These problems are more pronounced in tropical dryland fruit production (Somkuwar, 2018). Precision viticulture aims at reducing the input costs by following need-based cultural/crop protection practices; applying need-based inputs; increase grape yield and quality while minimizing environmental impact (Gebbers and Adamchuk, 2010). Vineyards are generally spatially variable and heterogeneous with regard to their location, soil quality, cropping practices and weather conditions (Bramley, 2003).

They, therefore, require specific cultural and crop-protection managements to address the real needs of the crop, in relation to these variabilities (Proffit *et al.*, 2006). Recent developments in new precision farming technologies for supporting vineyard management allows improved productivity, quality, food safety and at the same time, reduce environmental impact. The essential steps in precision viticulture are assessing variation and its management. Components that are responsible for vineyard performance in terms of yield and quality vary in space and time. The spatial variability in vineyards can be assessed and mapped using surveys, high resolution satellite/ aerial data and modeling.

Once variation is adequately assessed, accurate cultural (fertilizers, irrigations etc) and crop-protection (pesticides) inputs are applied in site-specific manner to reduce cost of cultivation and environmental impacts. Byju *et al.* (2020) developed fertilizer best management practices (FBMP) for three major cassava-growing regions of India using site-specific nutrient management (SSNM) and SSNM zonation maps for efficient use of fertilizers and getting better yields in cassava.

***Corresponding author :** naiksharmistha@gmail.com

PRECISION VITICULTURE

Precision viticulture is mainly used for optimization of inputs, differential grape harvesting, yield forecasting, and accuracy of canopy and soil sampling (Bramley and Lamb, 2003). In comparison to other crops, initiation of precision viticulture is of recent origin. This was due to the complexity of vineyard data, requirement of high-resolution images to differentiate canopy from soil and big data processing capacity to manage spatial information.

There are mainly two aspects of precision viticulture. These are monitoring technologies, that are used for mapping spatial variability and the technologies that are utilized to provide site-specific cultural inputs known as variable-rate technologies (VRTs) and robotics. In addition, supplementary technologies such as disease forecasting and Decision Support Systems (DSSs) also assist grape growers to take prophylactic actions. Available precision tools and their applications in viticulture are described below.

Information and communication technology (ICT)

Computers, mobile computing systems, internet and mobiles are major components for information gathering, processing and transferring. For collection of huge data from the fields mobile computing systems having high speed microprocessors that could operate at very high speeds were developed to store and transfer massive amounts of data. In addition to the computer hardware, there had been significant progress in development of precision farming software. Development of software for precision agriculture is more an experience than an application. The most important computer application in precision agriculture is Computer Vision (CV).

It is a technology that acquires, processes, analyses and extracts data of images to provide numerical or symbolic information such as the estimation or prediction of key traits of the targeted object, in a fast, contactless, reproducible and accurate manner (Vidal *et al.*, 2013). CV comprises a set of techniques associated with artificial intelligence, that allows a computer to understand and read an image to derive precise information (Ballard and Brown, 1982). Such type of electronic integration has played important role in furtherance of precision farming during the last few decades.

Monitoring technologies

Several technologies and sensors are deployed for acquiring intra-vineyard and inter-vineyard georeferenced information. Mainly two types of technologies, viz. remote sensing technologies and proximal sensing technologies are used to monitor vineyards.

Remote monitoring

Satellites, aircrafts and UAVs (unmanned aerial vehicles or drones) are being widely used in remote monitoring.

Satellites

The Global Positioning System (GPS) is a space-based satellite navigation system that provides highly accurate, rapid and timely information. The GPS receiver calculates position of the vineyard on earth (up to 15 m accuracy) based on the information it receives from more than 4 satellites. However, a network of fixed ground-based reference stations can correct the positions indicated by the satellite systems and provide location accuracy in centimeters. The first satellite, Landsat-1 launched in 1972 was equipped with multispectral sensor and provided a spatial resolution of 80 m with a revisit time of approximately 18 days. The last launched Landsat satellite, Landsat-8 (Ridwan *et al.,* 2018) operates in the visible, near-infrared, short wave infrared and thermal infrared spectrums. Other high-resolution satellites that are being used in remote sensing are:

Sentinel-2 (https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-2-msi),

RapidEye (https://earth.esa.int/eogateway/missions/rapideye?text=rapideye)

WorldView -1, -2 and -3 (https://earthdata.nasa.gov/worldview)

Sentinel-2 data are open-source and freely downloadable. RapidEye has been used to evaluate Normalized Differential Vegetation Index (NDVI) in order to characterize the vine vigor and some phenolic parameters. Simple linear relationships between NDVI at berry set, pre-veraison and ripening has been found to evaluate sugar content and anthocyanins at harvesting (Santangelo *et al.,* 2013). RapidEye has also been used to evaluate the Leaf Area Index (LAI) in vineyards demonstrating a good correlation with in-field estimation of evapotranspiration (Vanino *et al.,* 2015). WorldView has been used to detect vineyards,

canopy estimation and discrimination of varieties (Karakizi *et al.* 2016).

Aircrafts

Aircrafts monitor large areas with a long flight range and can carry heavy and multiple sensors at a time. Aircrafts provide better ground resolution (up to 10 cm) depending upon flying altitude. However, aircrafts are economically feasible only on areas bigger than 10 ha (Matese and Di Gennaro, 2015).

UAV

UAVs fly autonomously and can be controlled remotely by a ground pilot. UAVs are fixed with several flight control sensors (gyroscopes, compass, GPS, pressure sensor and accelerometers) which are controlled by a microprocessor. They can be equipped with a variety of sensors for performing a wide range of monitoring. UAVs provide very high spatial resolution on the ground (down to cm) and they are ideal for small-to-medium fields (1–20 ha), characterized by high fragmentation and high heterogeneity. There are two types of UAVs having rotary wings and fixed-wings. Rotary-wings UAVs having less flight time (up to 30 minutes) are generally used for monitoring small fragmented areas (up to 20 hectares), while *fixed*-wings UAVs having more flight time (up to 1 hour) allow monitoring large unfragmented flat areas (Ammoniaci *et al.,* 2021).

In comparison to satellites, UAVs have much higher resolution, therefore, use of UAVs with high-resolution sensors is suggested for assessing vine structure and inter-row spacing of vineyards (Khaliq *et al.* 2019). UAVs with true colour cameras (RGB) and multispectral or thermal sensors have been used in viticulture to detect vineyards/vine rows (Comba *et al.,* 2015); estimation of grape yield (Di Gennaro *et al.,* 2019); assessing vegetative vigor and detecting missing plants (Matese *et al.,* 2018); and estimating water stress and assessing grape maturity (Soubry *et al.*, 2018). UAV technology has shown to be economically compatible with the agronomic costs in vineyards with more than 40 hectares having lots of fragmented vineyards (Mondino *et al*, 2017).

Proximal monitoring

In addition to aerial monitoring, several tools having different types of sensers are available for proximal monitoring. Radiometric and fluorometric sensors and some application programmes such as VitiCanopy are used to assess canopy vigour, stress, chlorophyll content, nitrogen concentration and leaf area index. Geophysical and spectro-radiometric sensors are employed for assessing soil composition and structure. While, optical sensors (fluorometric and spectrophotometric sensors) determine grape quality and berry ripening. These sensors are mounted on farm machinery or some of them such as optical sensors are fixed on handheld devices and various measurements are carried by moving vehicles or manually for getting precise ground information. In addition, wireless sensor network (WSN) technologies configured in vineyards provide a highly useful and efficient tool for remote and real-time monitoring of important variables od vineyard.

Canopy assessment by proximal sensors

Radiometric sensors measure electromagnetic radiation reflected by vegetation and it can allow the rapid collection of important information for indirect measurement of the canopy state. The spectral response of canopy is mainly related to the radiation absorption by the pigments, which allows the assessment of vegetation cover but also the characterization of its health (Casa, 2017). If solar radiations or external light source is used, radiometric sensors are passive and results are affected by variations in lighting conditions.

But, if they use their own artificial light source, they are active and less affected by lighting variations. Also, use of inbuilt lighting by active sensors permits recording of information in night. Two commercially available radiometric sensors are OptRx (Ag Leader Technology, Ames, IA, USA) used to assess the vigor of the crop and CropSpec (Topcon, Livermore, CA, USA) used to determine chlorophyll content that can be correlated to nitrogen concentration in leaves.

Another optical sensor is fluorometer that measures fluorescence emitted by the chlorophyll. Based on this information onset of stress conditions in the vineyard can be predicted. The information derived from the fluorescence measurement represents functional state of the plant, and in turn photosynthetic potential of canopy. From this photosynthetic potential expressed as electronic transport rate (ETR) and two other parameters viz., leaf and air temperatures, Losciale *et al.* (2015) developed an index (I_{PL}) capable of estimating the rate of net photosynthesis of the leaves. Photosynthetic activity has been shown to influence fruit composition and wine quality in grape (Somkuwar *et al.*, 2014a, 2018).

VitiCanopy developed by De Bei *et al.* (2016) is one of the most used Apps to measure the LAI in vineyards. This is done through images acquired by a smartphone/tablet. The image is then analyzed by the App to calculate both the LAI and the porosity of the canopy. The results obtained through VitiCanopy are georeferenced to know the variation in the entire vineyard. Such information can be extrapolated to estimate the vigour, productivity and quality of produce from a vineyard.

Soil assessment by proximal sensors

Monitoring of soil health is one of the most important applications of precision viticulture. Wide range of sensors are used for assessing soil variability. Electrical conductivity (EC) of the soil is directly related with several soil properties such as texture, depth, water retention capacity, organic matter content and salinity. EC of the soil an be measured using mobile platforms equipped with sensors and GPS. Two types of sensors viz., Electrical Resistivity Sensors and Electromagnetic Induction Sensors are used to measure soil EC. Commercially available electrical resistivity sensors are Veris 3100 (Veris Technologies Inc, Salina, USA) and Automatic Resistivity Profiling System (Geocarta Ltd, Paris, France). While, DualEM (DualEM, Milton, Canada) and EM-31 & EM-38 (Geonics Ltd, Mississauga, Canada) are commercially available electromagnetic induction sensors. Knowledge about spatial variability of soil characteristics is important for understanding variability in the physiological response of the vines (Priori *et al.* 2019).

Other type of sensors used for soil assessment are Geophysical sensors. These sensors measure potential drop in introduced current in the soil. Such drop is related with EC. The EC of the soil is related to the soil texture, humidity, salinity, degree of compaction and the presence of gravel and pebbles in the soil. Invasive geophysical sensors (mobile soil resistance-meters) measure the apparent resistivity of the soil by using direct contact electrodes and non-invasive sensors (electromagnetic induction sensors, ground penetrating radars) assess soil properties by using electromagnetic fields. Another type of non-invasive sensor is the ground penetrating radars. These radars gather information of the soil through emission of electromagnetic pulses and phenomena of reflection and refraction of the different materials of soil.

Third type of sensor used for assessing soil is Spectroradiometer. Each soil has its own spectral signature which is the intensity of the reflected radiation depending on the intrinsic spectral behavior of soil constituents (minerals, organic matter, water etc). Gamma-ray based spectroradiometers consist of a scintillator crystal, generally, made of cesium iodide (Csl) or sodium iodide (Nal), which emits photons when hit by gamma rays. Reflected photons by the soil are measured to characterize soil properties. Vis-nir reflectance spectroradiometer is rapid and relatively cheap alternative to gamma-ray based spectroradiometer. This sensor can measure several soil properties in a single scan.

Grape quality assessment by proximal sensors

Berry quality is an important attribute from commercial angle and several cultural manipulations are made to improve bunch yield, berry quality and biochemical composition of berries (Somkuwar *et al.*, 2014b). Non-destructive monitoring of grape quality parameters is based on optical sensors. Manual devices or tools fixed with optical sensors are used for non-destructive monitoring of grape quality parameters. Some of the tools that are in common use are: Multiplex (Force-A, Orsay, France) and Spectron (Pellenc SA, Pertuis, France). Multiplex is mainly used to estimate the nitrogen status of grapevine leaves.

In addition to nitrogen status, Multiplex can also assess contents of chlorophyll, flavanols and anthocyanins in the leaves and grapes (Cerovic *et al.*, 2008). Another sensor used to assess the quality of the grapes is the Spectron (Pellenc SA, Pertuis, France). This sensor is integrated with GPS and can be used for non-destructive measurements of quality-related parameters, like sugar, acidity, anthocyanins and water content (Matese and Di Gennaro, 2015).

Yield assessment by proximal sensors

Many systems are available to obtain georeferenced yield information. These are: HarvestMaster Sensor System HM570 (Juniper Systems Inc., Logan, USA), Canlink Grape Yield Monitor 3000GRM (Farmscan, Bentley, WA, Australia), and Advanced Technology and Viticulture (ATV) (Advanced Technology Viticulture, Joslin, SA, Australia). These systems are mounted on mechanical harvesters and for yield assessment they use volumetric grape measurement on the discharge conveyor belt of the harvester and/or direct measurement of the transported grape weight by means of load cells.

Assessment of microclimate and other parameters in vineyard using Wireless Sensor Network

Wireless sensor network (WSN) technologies provide a useful and efficient tool for remote and real-time monitoring of important variables of a vineyard. A WSN consists of wireless peripheral nodes and a sensor board equipped with sensors and a wireless module for data transmission from nodes to a base station. At base station the data are stored and these data accessible to the end user for taking appropriate vineyard management decisions. Applications and configuration of WSN in vineyards has been adequately described (Burrell *et al.*,2004) and WSN has been successfully used for prolonged temperature and microclimate measurements (Matese *et al.*, 2013). The primary application of WSN is the acquisition of micrometeorological parameters at vine canopy and soil level. Recent developments of new kinds of sensors such as dendrometers and sap-flow sensors made it possible to continuously measure plant water status for irrigation scheduling.

Forecasting and decision support systems (DSSs)

Precision viticulture aims at reducing input costs; enhancing productivity and quality of the produce; and protecting environment. Reliable and timely forecasts provide useful information for planning in advance. Viticulture is highly input and cost intensive. In crops, production and attack of insect pests and diseases and production estimates are the two major aspects that need attention. Insect pests and diseases are major causes of reduction in productivity and their appearance and intensity can be forecasted based on weather parameters. Timely application of remedial measures reduces the yield loss.

Forecasts of crop production before harvest are required for different policy decisions related to storage, value addition, pricing, marketing, import-export, etc. Other tools for timely application of inputs are Decision Support Systems (DSSs). Decision support systems (Power, 2002) are interactive, computer-based systems which help users to accurately identify specific problem (mainly nutrient deficiency and incidence of insect pest/disease) based on symptoms in the vineyard. Once the problem is identified, DSS suggests management strategies for it.

In viticulture, DSSs have been of great help in making appropriate decisions at appropriate time, thereby, reducing crop losses to a greater extent. Several DSSs are available for guiding the vine growers to take suitable management strategies to address macro- and micro-fertilizer deficiencies, incidence of diseases and infestations by inset pests. Metos® (Pessl Instruments GmbH, Werksweg, Weiz, Austria) is commercially available decision support system for grape production.

ICAR-National Research Centre for Grapes, Pune, India (https://nrcgrapes.icar.gov.in) has developed some DSSs on irrigation, soil nutrition, diseases and insect pests for assisting Indian grape growers for judicious use of inputs.

Variable rate technology (VRT)

Farm machines fitted with VRT technology (sensors) and GPS make precise operations based on prescription maps prepared using remotely and proximally recorded data of the vineyard. Based on these prescriptions, these VRT machines apply various inputs (fertilizers, pesticides and other inputs) at right doses and at right places without manually changing rate settings. This is possible due to GPS module and electronics, consisting of control units and proportional servo-valves mounted on VRT machine. In order to have a standardized system of communication between tractors, software and various equipment and to allow the exchange of data and information with a universal language through a single control console integrated in the tractor cab, the ISOBUS or ISO 11783 protocol has been developed (ISO Standard. Available online: https://www.iso.org/standard/57556.html

In addition to fertilizers and pesticide applications, such thematic prescription maps can be developed for yield and quality parameters like acidity, polyphenols and anthocyanin. Another application of VRT machines is selective harvesting. Selective harvesting is split picking of fruit according to a vineyard vigor mapping, grape composition, and quality as per market demand. For example, grapes grown for juice purpose, sugar content is an important target for harvest, while, combinations of sugar content, anthocyanin content and acidity could be targets for grapes grown for wine purpose.

It has been reported that a variable rate fertilization can save up to 30% of fertilizers (Donna *et al.*, 2013) and a variable rate application of pesticides can save up to 30% of pesticides and increase the profit up to 20% (Casa, 2017).

Robots

The use of robotics in agriculture is still in infancy, however, the agricultural robotics is poised to change agricultural scenario in the world by 2050 (Blackmore, 2014). In viticulture, The VineRobot project at the University of La Rioja, Spain is aimed to develop a new agricultural robot, equipped with noninvasive monitoring technologies and GPS. Such robots are expected to perform a proximal monitoring of various critical parameters such as yield, vigor, water stress, quality of the grapes and assist vine growers to improve vineyard management. The Commercially available Wall-Ye robot (http://www.wall-ye.com/) can move along vine rows and acquire data on each vine, thereby, producing detailed vineyard map. Wall-Ye can prune about 600 plants per day and can be remotely controlled by iPad.

Another robot called VineGuard developed by Ben-Gurion University, Israel is designed for foliar applications. This robot can move within the vineyard using a complex set of sensors. Another commercially available robot is "Vitirover" (https://www.vitirover.fr/en-home). This robot was developed by Chateau Coutet (Saint Emilion, France) and it can cut the weeds up to a distance of 2–3 cm from the base of the vine. Solar power system is fixed on this robot. Several other robots and robotic tractors are under various stages of development and testing.

Precision technologies in viticulture

The introduction of new technologies for vineyard management facilitate enhancement in efficiency, productivity and quality and reduction in cost of cultivation and environmental impact. Precision technologies have been used for various purposes in vineyards.

Soil properties

Variations in soil fertility impact vineyard performance. Mobile platforms fitted with proximal soil sensors can be moved over the field to acquire geo-referenced soil data. High-resolution maps developed using this soil data and GPS provide valuable soil information on spatial variability of soil properties and topography which are relevant when establishing new vineyards and/or redeveloping existing vineyards (Bramley, 2010). Data acquired from Recently, data acquired from electromagnetic induction sensors and multispectral imaging were combined to estimate vineyard soil and vine vigour variability (Hubbard *et al.*, 2021).

Use of electrical resistivity sensors is limited to determination of soil nutrients, pH and organic matter; however, optical and electrochemical sensors can be used for assessing patterns of chemical fertility parameters of the soil (Joseph *et al.*, 2010). Performance of mobile near infrared spectrometry for in situ soil mapping and gamma-ray spectrometers for detecting the presence of particular minerals have been explored in vineyards by Schirrmann *et al.* (2013) and Simone *et al.* (2014), respectively.

Vegetative growth, nutritional status and canopy architecture

Remote and Proximal Sensing-Derived Spectral Indices and Biophysical Variables have been widely employed to evaluate vine canopy growth and health in commercial vineyards (Darra *et al.*, 2021). Nutritional status of leaf nitrogen can either be assessed using fluorescence-based portable sensors. Such sensors can also be mounted on mobile platforms (Diago *et al.*, 2016a) Another technology known as light detection and ranging (LiDAR) has been shown to be a powerful technology for the rapid and non-destructive assessment of canopy and leaf parameters in vineyards (Arno *et al.*, 2013). Some other precision viticulture applications are RGB camera imagery acquired by UAV for estimating canopy biomass and detecting missing plants (Di Gennaro and Matese, 2020) and UAV-based point cloud analysis to detect the severity in canopy decline caused by dieback-like disease symptoms (Ouyang *et al.* 2021). Canopy architecture, including fruit and leaf exposure and canopy porosity can assessed using machine vision technologies (Diago *et al.*, 2016c) or on-the-go assessment using RGB image analysis (Diago *et al.*, 2019). "VitiCanopy" App uses smartphones as imaging devices to measure vine performance attributes such as canopy vigour, LAI and porosity (De Bei *et al.*, 2016).

Pests and diseases

Grape cultivation in India faces serious threats from several diseases and insect pests. Major fungal diseases are downy mildew, powdery mildew and anthracnose, whereas, mealybug and thrips are major insect pests that cause enormous economic losses to grape cultivation. Among these, Downey mildew is one of the serious diseases in many horticultural crops (Somkuwar and More, 1996) including grapes. Use of appropriate pesticide in right dose at right

time and right place holds the key for effective pest management.

Visual inspection of diseases and insect pests is time consuming, subjective, risky and expensive. Use of new sensors and monitoring tools has been shown to provide objective, rapid, cheap and reliable diagnosis of pests and diseases in vineyards (Lee and Tardaguila, 2021). These technologies have opened new frontiers to map disease/pest across vineyards in order to apply fungicides differentially using VRT technology (Chen *et al*., 2020). Using computer vision and deep learning, Gutierrez *et al.* (2021b) could detect and differentiate downy mildew and spider mite in commercial vineyards.

Computer vision, hyperspectral imaging and machine learning have been applied for assessing downy mildew in grapevines (Rose *et al*., 2016). Use of hand-held UV-LED fluorimeter for early detection of stilbenoid phytoalexins associated with Downey mildew infections on grape leaves was reported by Latouche *et al.* (2015). Wine producers set tolerance levels for diseases such as powdery mildew and Botrytis bunch rot. Two apps have been released (PMapp® and RotBot®) which allow users to quickly assess the severity of these diseases on clusters and calculate both the incidence and severity of the disease and also record other parameters such as date, time and geo-reference position (Hill *et al*., 2014; Birchmore *et al*., 2015).

Forecasting models and DSSs are valuable tools to manage biotic stresses in viticulture. During the last few years several computer-based disease and insect pest prediction models and decision support systems (DSS) have been developed in many crop plants including grapes. Rosa *et al.* (1993) developed PLASMO (*Plasmopara* Simulation Model) model for forecasting downy mildew in *Vitis vinifera*. The model simulates the development of downy mildew on the basis of climatic conditions.

Chen *et al.* (2020) developed an efficient and accurate machine learning algorithms for predicting Downey mildew that reduced at least 50% of fungicide use in Bordeaux region of France. Brischetto *et al.* (2021) developed a mechanistic model to predict secondary infections of *Plasmopara viticola* and their severity as influenced by environmental conditions. Powdery mildew caused by *Uncinula necator* fungus is another important disease of grapes. Fungal growth, conidia formation and germ tube formation are mainly influenced by temperature. Management strategy of Powdery Mildew disease on grapes by a decision support system based on weather and image processing was developed by Mundankar *et al.* (2007).

In warm tropical and sub-tropical conditions, anthracnose disease caused by *Colletotrichum gloeosporioides* affects tender shoots and young fruits reducing vine productivity and fruit quality. Disease incidence and severity have been shown to be dependent on weather parameters. Ghule *et al.* (2015) reported favourable weather conditions for development and progression of anthracnose. These were rainfall with minimum temperature between 22.33 to 23.12 ^{0}C, maximum temperature between 30.12 to 31.88 ^{0}C, RH-1 more than 67% and RH-2 more than 51%.

In India, major insect pests in grapes are mealybugs, thrips, flea beetle, leafhoppers, stem borer and mites in order of their economic damage to the crop. Indiscriminate use of pesticides not only increases cost of cultivation but also is harmful to the environment and human health. Therefore, pest management in viticulture should follow an integrated approach, including best agronomic practices, advance forecasting using models, decision support systems (DSSs), biological control agents and chemical sprays for reducing pesticide use (Pertot *et al*., 2017). Chougule *et al.* (2019) developed a grape crop protection decision support system named as "PDMGrapes" using ontology, semantic web rule language and image processing techniques for management of insect pests and diseases on grapes in hot tropical region of India.

Lessio *et al.* (2021) have reviewed mathematical models and DSSs developed to predict key aspects of insect pests. These models are used for forecasting seasonal occurrence and spread of insect pests. Under integrated pest management (IPM), one of the most important components is the reduction in number of pesticide sprays and pesticide doses. Roman *et al.* (2022) developed DOSA3D decision support system that allows the dose to be adjusted to the specific scenario. DOSA3D calculates the optimal application volume rate by estimating the leaf area index and takes into account the overall spraying efficiency and the pest or disease to be controlled. DOSA3D could achieve pesticide savings up to 53% in fruit trees and 60% in vineyards.

Water status in vineyard

Current changing climates are characterized by water scarcity and higher temperatures; therefore,

assessment of vineyard water status and irrigation management are becoming increasingly important. Thermal imaging technology has been used extensively to determine vineyard water status manually (Grant *et al.*, 2016) or remotely using aerial platforms (Bellvert *et al.*, 2014). Thermographic instrument can also be mounted to a ground-based vehicle for on-the-go mapping of vine water status in commercial vineyards (Gutierrez *et al.*, 2021a). Small thermal camera attached to a smartphone has also been used for assessing vine water status (Petri *et al.*, 2019). Recently, near infrared spectrometers mounted on mobile platforms have been used to assess vine water status in a stop-and-go mode (Diago *et al.*, 2017). A mobile phone application (ApeX-Vigne) has also been developed for monitoring vine water status in vineyards (Pichon *et al.*, 2021).

Yield components and crop forecasting

During harvesting of grapes, yield can be easily monitored by measuring the weight of berries flowing across load cells fitted to mechanical harvesters (Taylor *et al.*, 2019). Computer vision systems have recently been used to assess grape yields based on cluster compactness (Palacios *et al.*, 2019), number of berries per cluster (Aquino *et al.*, 2018), cluster weight (Liu *et al.*, 2020b) and berry size (Roscher *et al.*, 2014). Three android-based Apps viz., vitisFlower® (Aquino *et al.*, 2015), vitisBerry® (Aquino *et al.*, 2015) and 3DBunch® (Liu *et al.*, 2020a) have been developed for measurements of flower, berry and bunch parameters. For assessing large commercial vineyards, automatic RGB image capturing gadgets are mounted on mobile vehicles and yield predictions are made using computer vision technology (Palacios *et al.*, 2020).

In addition to these techniques, mathematical models are also used to predict annual yields in in many horticultural crops. Jaslam *et al.* (2022) used 44 years (1974-75 to 2018-19) vegetable production data to forecast vegetable production in the next five years starting from 2019-20 in UAE. For onions and green shallots, linear trend model was selected as the best fit, whereas, simple exponential smoothing model was most suitable in cauliflowers, broccoli, pumpkins, squash, gourds and spinach. The optimum model obtained for forecasting carrots and turnips was Holt's linear exponential smoothing model and ARIMA model was the best fit for the rest of vegetable groups.

Fruit composition and quality attributes

Near infrared spectral analyzers are capable of monitoring dynamic changes in berry composition during the ripening period and, therefore, provide an alternative option to destructive quality testing procedures. Portable near infrared spectrometers have been used for determining total soluble solids and other compositions in grape berries under both laboratory and field conditions (Barnaba *et al.*, 2013) This technology has also been successfully implemented on-the-go from a moving vehicle to monitor the dynamics of berry ripening in the vineyard (Fernandez-Novales *et al.*, 2019).

Another non-destructive technology consisting of hyperspectral imaging (HIS) to fingerprint the colour pigments of whole grape berries has also been developed for laboratory testing (Diago *et al.*, 2016b) and on-the-go from a mobile platform in the vineyard (Benelli *et al.*, 2021). A chlorophyll fluorescence-based sensor Multiplex® (FORCE-A, Orsay, France) has been developed for contact-free measurement of anthocyanin content in grape berries under laboratory (Ben Ghozlen *et al.*, 2010). These sensors can be mounted on harvesters for data acquisition on-the-go (Bramley *et al.*, 2011) Computer vision technology is also being used for sorting berries in many wineries before crushing. Vegetation indices derived from remote and proximal sensors were also used to evaluate quality characteristics of table grapes (Anastasiou *et al.*, 2018). Proximal sensing proved to be more accurate in terms of table grape yield and quality characteristics compared to satellite-based monitoring.

CONCLUSION

Choosing appropriate technologies for different types of application is important in precision viticulture. Though satellites and aircrafts are excellent tools for developing prescription maps for VRT machines, satellites have low resolutions and operational cost of aircrafts is high. In this regard, UAV platforms give high resolution, flexibility of use and economic feasibility. However, they can only monitor small areas. VRTs are well-developed and widely used, especially in chemical applications. Remote and proximal monitoring technologies and VRT machinery are being extensively used in some parts of the world, while robotics is in an experimental stage. In India, where majority of vineyards are small and

fragmented, use of expensive precision technologies may not be feasible. However, at village/block/district level some of these technologies like UAV and proximal sensors can be adopted by farmers' cooperatives to make viticulture technologically, economically and environmentally sustainable.

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Research Article

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Bulb preservation influenced by various temperature and media on flower and bulb production in Lilium (*Lilium* spp.)

Farjana N Khan, K Ambia, A Naznin, MMR Bhuiyin and MT Rashid

Horticultural Research Centre, BARI, Gazipur 1701 (Bangladesh)

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ABSTRACT

The experiment was conducted with three levels each of storage temperature (2.1-2.5^{0}c, 6.5-7.5^{0}c and 8.0-10°c) and preservation media (sawdust, cocodust and combination of both in equal quantities) from June 2019 to May 2020 at Floriculture Division, Horticulture Research Centre, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh, to find out the optimum storage temperature and suitable media for Lilium (*Lilium* spp.) bulb preservation and also to see their effect on flower and bulb production in the next flowering season. The bulbs under cool temperature (2.1-2.5^{0}c) with sawdust produced minimum sprout (22.0%), shorter root (3.25cm) and shoot (0.55cm) and gained the minimum weight 30, 60, 90 and 120 days after storage (1.42, 2.35, 3.07 and 3.20%, respectively) which ultimately protected bulbs from deterioration during storage period. The two other temperature (6.5-7.5^{0}c and 8.0-10.0^{0}c) including all media produced 100% sprouting and poor performance in other parameters. Though non-significant variations were recorded in flower, bulb and bulblet production from bulbs kept in storage in relation to combination of temperature and media but bulbs preserved in various media at cool temperature (2.1^{0}c-2.5^{0}c) showed better performances on growth, flowering, bulb and bulblet production in next flowering season.

Key words: Bulb preservation, Temperature, Media, Flower, and Bulb production

Lilium *(Lilium* spp.*)* is a high demanded cut flower in world flower market (Lucidos *et al*., 2013). To meet its local demand, its flowers are imported (Khan and Ambia, 2018). Considering its market demand, farmers in Bangladesh are very much interested in its cultivation. Bulb preservation is an important issue for commercial cultivation. Shin *et al*. (2002) showed that low temperature is necessary for sprouting of bulbs after harvesting. Vernalization is affected by combination of temperature and duration of storing period (Le Nard and De Hertogh, 1993). According to Boontjes (1983) and Beattie and White (1993), bulbs of Asiatic hybrids, Oriental hybrids and *L. longiflorum* are stored in moist peat at -2 °C for year-round forcing. Maddah *et al*. (2012) showed that after 10 weeks of vernalization most of bulbs were stimulated. But in Bangladesh climatic condition, 10 weeks are not sufficient to keep its bulbs in storage. Besides, a certain level of postharvest rots of lilium bulbs occurred due to its perishable nature. Moist cocodust is being used widely for lilium bulb preservation (Malik, 2017). Therefore, an experiment was conducted to standardize optimum storage temperature and suitable preservation media for its bulb preservation and also to see effect of storage temperature and preservation media on flower and bulb production in the next flowering season.

MATERIALS AND METHODS

The experiment was conducted at Bangladesh Agricultural Development Corporation (BADC) cold storage of Kashimpur, Postharvest Division's cool room of Bangladesh Agricultural Research Institute (BARI) and Constant temperature and humidity chamber of Horticulture Research Centre (HRC), BARI, Gazipur, during June 2019 to October 2019 to see the behaviour of bulbs in storage. Later on, experiment was continued at Floriculture Research Field, HRC, BARI during November 2019 to May 2020 to observe its flowers, bulbs and bulblet production from stored bulbs. The bulbs of BARI Lilium-1 (Asiatic group and flower creamy white in colour) were used.

There were two factors, viz. storage temperature @ 2.1-2.5^{0}c, 6.5-7.5^{0}c and 8.0-10°c considered as one factor and preservation media like sawdust (100%),

Corresponding author : farjanakhan2015@gmail.com

cocodust (100%), and sawdust+cocodust (50:50) were considered as another factor. The bulbs were kept in plastic crate at cold storage at per treatments in June 2019. Various growth parameters of lilium bulbs during storage period were recorded. After completion of storage period, bulbs were planted in November 2019 under shade net. In field, unit plot size was 1.2 m × 1.50 m and spacing was maintained at 15cm × 15cm. No chemical fertilizer up to 3 weeks of bulb planting was applied.

After 3 weeks of bulb planting, NPK@30:20:20g/m^2 was applied. Urea and MoP @ 100kg/ha were topdressed before spike initiation stage and bulb lifting, respectively. Cultural practices, weeding and watering were done as per the requirement. Mulching with straw was done when temperature got high. Netting (GI wire and nylon thread) was given to support the plants. The plants were protected from birds and other harmful animals using net made of nylon threads. Carbendazim (Autostin) was sprayed @ 1g/L of water at 15 days interval starting from 20 days after planting to protect the plants from botrytis blight disease. Simultaneously, neem oil and Biomax (1 ml/L) were used to protect from aphids and beetles. The flower spikes were harvested when lower most buds showed colour.

During flower harvesting, plants were kept leaving 25-30cm stem in field for bulb development. When leaves were brown and more or less damaged bulbs were lifted carefully and stored at 2.1-2.5^{0}c temperature for next planting. Various quantitative data regarding flower, bulb and bulblet production were recorded from ten randomly selected plants from each unit plot. The CRD factorial was followed for storage experiment and RCB factorial design was followed for field experiment. The data were analyzed statistically by using R software to find out the variation among different treatments. Treatment means were compared by LSD (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Effect of temperature and media on growth

During storage period bulbs growth was significantly influenced by various storage temperature and media (Table 1). Cool temperature (2.1-2.5^{0}c) showed significantly less sprout initiation

Table 1: Effect of storage temperature and media on growth of bulbs during storage

Treatment	Sprout initiation (%)	Root number/bulb	Average root length (cm)	Average shoot length (cm)
	Temperature			
2.1-2.5^{0}c (T_1)	65.0 b (51.83)	9.55 c	4.0 c	0.58 c
6.5-7.5^{0}c (T_2)	100.0 a (86.04)	12.98 b	11.75 b	10.20 b
8.0-10.0^{0}c (T_3)	100.0 a (86.04)	15.0 a	16.45 a	13.10 a
Level of significance	**	*	**	**
	Media			
Sawdust (M_1)	72.0 c (56.0)	12.83 a	7.75 c	5.78 c
Cocodust (M_2)	98.50 a (80.04)	11.52 b	13.83 a	10.24 a
50% sawdust+50% cocodust (M_3)	90.0 b (69.04)	12.12 ab	10.38 b	7.80 b
Level of significance	**	*	**	**
CV(%)	4.48	6.20	13.0	11.12

Figures in parentheses are transformed value

Means with the same letter(s) are not significantly different

** significant at 1%; * significant at 5%

(65.0%), minimum number of roots/bulb (9.55) and shortest root and shoot (4.0 and 0.58cm, respectively). The higher temperature (8.0-10.0^{0}c) showed poor performances. As per Yu-Fang and Qiu-Rong (2016), low temperature storage can keep the activity of related enzymes to delay senescence and browning thus sprouting will be less. The starch contents decreased continuously in interior and exterior scales, while contents of total soluble carbohydrates and reducing sugar increased at low temperature. But due to low respiration rate, there was a minimal consumption of carbohydrates.

Considering preservation media, sawdust showed lower number of sprout initiation (72.0%), shorter root (7.75cm) and shoot (5.78cm). Though sawdust produced maximum number of roots/bulb (12.83), followed by mixture of sawdust and cocodust (12.12) but overall good performances was shown by sawdust. Finley (2021) showed that bulbs should be stored in container with peat moss, sawdust or vermiculite which supported our study. Beattie and White (1993) used moist cocodust as preservation media for bulbs storing at -2 °C for year-round forcing.

Combined effect of temperature and media

Combined effect of temperature and media showed significant variations on all the parameters during storage period except roots/bulb (Table 2). The cool temperature (2.1-2.5^{0}c) with sawdust produced minimum sprouts (22.0%), shorter root (3.25cm) and shoot (0.55cm). At temperature (6.5-7.5^{0}c and 8.0-10.0^{0}c) including all media produced 100% sprouting. The bulbs under high temperature (8.0-10.0^{0}c) with cocodust produced longest root (21.0) and shoot (16.85cm).

Effect of temperature and media on weight of bulbs

Changes in bulb weight (%) at various days after

Table 2: Combined effect of temperature and media on growth of bulbs during storage

Treatment	Sprout initiation (%)	Roots number/bulb	Average root length (cm)	Average shoot length (cm)
T_1 M_1	22.0 c (26.98)	10.12 cd	3.25 c	0.55 d
T_1 M_2	96.20. a (75.98)	9.47 d	5.43 c	0.77 d
T_1 M_3	78.0 b (59.84)	9.65 d	3.67 c	0.58 d
T_2 M_1	100.0 a (86.04)	13.0 b	6.40 c	7.48 c
T_2 M_2	100.0 a (86.04)	12.15bc	15.45 b	12.67 b
T_2 M_3	100.0 a (86.04)	12.80 b	12.45 b	9.68 c
T_3 M_1	100.0 a (86.04)	15.75 a	13.65 b	9.60 c
T_3 M_2	100.0 a (86.04)	13.51 ab	21.0 a	16.85 a
T_3 M_3	100.0 a (86.04)	14.18 ab	15.21 b	13.0 b
Level of significance	**	NS	**	**
CV(%)	4.48	6.20	13.0	11.12

Figures in parentheses are transformed value

Means with the same letter(s) are not significantly different

** significant at 1%; NS, non-significant

Where, T_1, 2.1-2.5^{0}c M_1, sawdust (100%)

T_2, 6.5-7.5^{0}c M_2, cocodust (100%)

T_3, 8.0-10.0^{0}c M_3, sawdust+cocodust (50:50)

storage were significantly influenced by various temperatures (Fig. 1). At 30 Days after storage (DAS), the minimum weight (3.02%) was gained at 2.1-2.5^{0}c which gradually increased 8.89% up to 120 DAS. Whereas, high temperature (8.0-10.0^{0}c) showed 10.25% increase in bulb weight at initial stage (30 DAS) which turned 23.80% at storage ending period (120 DAS). The sawdust significantly showed less increase in bulb weight at 30, 60, 90 and 120 DAS (3.45%, 4.78%, 6.31% & 9.32%, respectively) (Fig. 2). In contrast, the bulbs preserved by cocodust gained significantly higher weight at various storage periods (9.37%, 12.36%, 17.33% & 26.81%, respectively).

Combined effect of temperature and media

Changes in bulb weight (%) at various storage dates were significantly influenced due to combined effect of temperature and media (Table 3). The bulbs with sawdust preserved at low temperature (2.1-2.5^{0}c) gained minimum weight during storage period (1.42%, 2.35%, 3.07% and 3.20%, respectively) which ultimately protected bulbs from deterioration. Maddah *et al*. (2012) reported that vernalization temperature of 3°C has preferred to 9°C for *Lilium ledebourii's* bulb preservation because at 9°C starch hydrolyzed and soluble sugar consumption were decreased. The consumption rate of sugar stored in plant storage organs slows down by lowering their respiration (Salisbury and Ross 1992). Whereas bulbs at high temperature (8.0-10.0^{0}c) with cocodust gained maximum weight 30, 60, 90, and 120 DAS (17.58, 22.73, 26.06 and 36.07%, respectively) which may be due to higher sprout initiation, longer root and shoot produced during entire storage period.

Effect of temperature and media on growth and flower from stored bulbs

The growth and flower production showed significant variation at various temperatures except emergence (%) (Table 4). Significantly longer plant (62.50 cm), spike (82.10cm) and rachis (29.35cm), maximum number of florets (6.75) and also larger floret (16.45cm) were recorded from bulbs kept at 2.1-2.5 °c during storage.

The bulbs preserved with various media did not show significant differences on growth and flower production except spike length (Table 4). The longest spike (67.90 cm) was produced by bulbs preserved in sawdust media followed by 50%sawdust+50%cocodust (65.50cm).

Combined effect of temperature and media

Non-significant variations were recorded in flower production from bulbs kept in storage in relation to combination of temperature and media (Table 5). But bulbs preserved in various media at cool temperature (2.1^{0}c-2.5^{0}c) showed better performance for growth and flowering parameters.

Effect of temperature and media on bulb and bulblet production from stored bulbs

All the parameters of bulb and bulblet production were significantly influenced by bulbs preserved at various temperatures during storage (Table 6). Bulbs preserved in cold storage (2.1-2.5^{0}c) produced significantly higher number of bulbs/plant

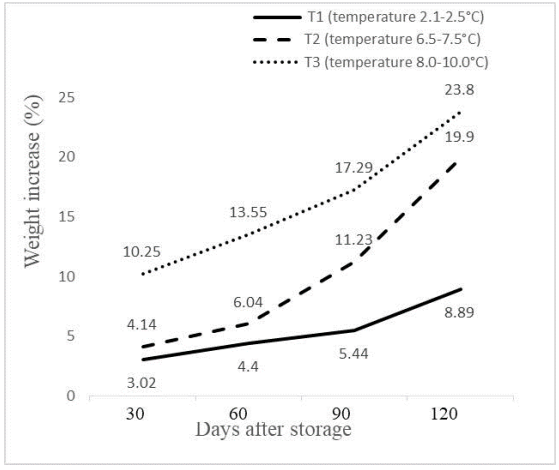

Fig.1. Increase in bulb weight (%) influenced by various temperature during storage period where, T_1, 2.1-2.5^{0}c T_2, 6.5-7.5^{0}c, T_3, 8.0-10.0^{0}c

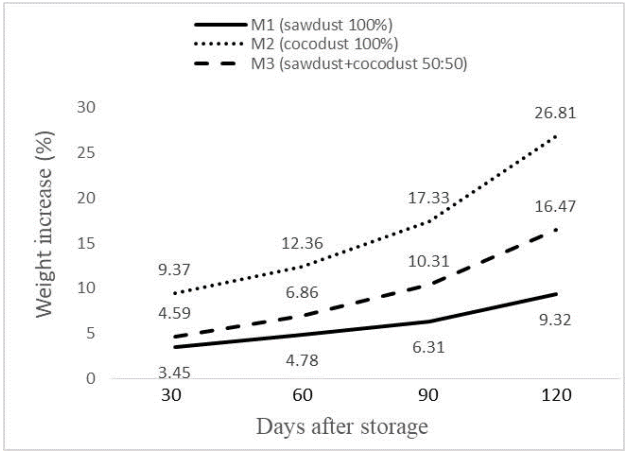

Fig. 2. Increase in weight of bulb (%) influenced by various media during storage period where, M1, sawdust (100%) M, cocodust (100%) M, sawdust+cocodust (50:50)

Table 3: Combined effect of temperature and media on changes of weight of lilium bulbs during storage period

Treatment	Changes of weight (%)			
	30 DAS	60 DAS	90 DAS	120 DAS
$T_1 M_1$	1.42 d	2.35 e	3.07 e	3.20 f
	(1.12)	(1.53)	(1.73)	(9.81)
$T_1 M_2$	4.99 bc	6.65 bcd	8.31 cd	14.07 cd
	(2.23)	(2.58)	(2.88)	(21.25)
$T_1 M_3$	2.65 cd	4.21cde	4.94 de	9.41e
	(1.62)	(2.04)	(2.2)	(17.22)
$T_2 M_1$	3.10 bcd	4.14 de	5.07 de	11.92 de
	(1.73)	(2.02)	(2.24)	(19.47)
$T_2 M_2$	5.53 bc	7.71bcd	17.61 ab	30.30 a
	(2.34)	(2.76)	(4.18)	(32.18)
$T_2 M_3$	3.79 bcd	6.29 bcd	10.99 bc	17.48 bc
	(1.92)	(2.50)	(3.31)	(23.82)
$T_3 M_1$	5.85 bc	7.85 bc	10.79 bc	12.83 cde
	(2.40)	(2.80)	(3.28)	(20.23)
$T_3 M_2$	17.58 a	22.73 a	26.06 a	36.07 a
	(4.18)	(4.75)	(5.09)	(35.59)
$T_3 M_3$	7.33 b	10.08 b	15.0 b	22.51b
	(2.69)	(3.17)	(3.87)	(27.32)
Level of significance	*	**	*	*
CV(%)	14.96	9.90	10.56	5.79

Figures in parentheses are transformed value

Means with the same letter(s) are not significantly different

**, significant at 1%; *, significant at 5%

where, T1, 2.1-2.50c M1, sawdust (100%)

T2, 6.5-7.50c M2, cocodust (100%)

T3, 8.0-10.00c M3, sawdust+cocodust (50:50)

Table 4: Performance of flower production of lilium from bulbs kept in storage in relation to the temperature and media

Treatment	Emergence (%)	Plant height (cm)	Spike length (cm)	Rachis length (cm)	Florets/ spike	Floret diameter (cm)
			Temperature			
2.1-2.5^{0}c (T_1)	100.0 (9.99)	62.50 a	82.10 a	29.35 a	6.75 a	16.45 a
6.5-7.5^{0}c (T_2)	96.66 (9.89)	53.75 b	58.25 b	18.29 b	2.42 b	16.10 ab
8.0-10.0^{0}c (T_3)	98.32 (9.83)	51.30 b	55.0 b	18.10 b	2.37 b	15.77 b
Level of significance	NS	**	**	**	**	*
			Media			
Sawdust (M_1)	99.43 (9.97)	58.0	67.90 a	23.66	4.50	16.33
Cocodust (M_2)	96.66 (9.83)	54.56	63.830b	21.89	3.46	15.86
50% Sawdust+50% Cocodust (M_3)	98.32 (9.91)	56.30	65.50 ab	22.68	3.86	15.98
Level of significance	NS	NS	*	NS	NS	NS
CV(%)	1.44	5.88	4.50	7.57	24.50	2.96

Figures in parentheses are transformed value

Means with the same letter(s) are not significantly different

**, significant at 1%; *, significant at 5% ; NS, non-significant

Table 5: Performance of flower production of bulbs kept in storage in relation to combination of temperature and media

Treatment	Emergence (%)	Plant height (cm)	Spike length (cm)	Rachis length (cm)	Florets/ spike	Floret diameter (cm)
T_1 M_1	100.0 (9.99)	63.50	84.0	30.73	7.20	16.84
T_1 M_2	100.0 (9.99)	60.0	79.77	28.67	5.95	16.21
T_1 M_3	100.0 (9.99)	62.68	82.53	29.50	6.87	16.35
T_2 M_1	100.0 (9.99)	56.33	61.0	18.90	2.75	16.15
T_2 M_2	94.99 (9.74)	52.58	55.52	17.80	2.36	15.88
T_2 M_3	98.32 (9.91)	53.60	57.31	18.43	2.49	16.13
T_3 M_1	98.32 (9.91)	52.67	55.57	18.69	2.61	15.97
T_3 M_2	94.99 (9.74)	48.45	54.31	17.87	2.24	15.55
T_3 M_3	96.66 (9.83)	51.33	54.65	18.50	2.41	15.62
Level of significant	NS	NS	NS	NS	NS	NS
CV(%)	1.44	5.88	4.50	7.57	24.50	2.96

Figures in parentheses are transformed value

Means with the same letter(s) are not significantly different

NS, non-significant

Where, T_1, 2.1-2.50c M_1, sawdust (100%)

T_2, 6.5-7.50c M_2, cocodust (100%)

T_3, 8.0-10.00c M_3, sawdust+cocodust (50:50)

(1.98), heaviest and largest bulbs (29.94g and 4.93cm, respectively) and maximum number and weight of bulblets/plant (2.45 and 2.79g, respectively). Tang *et al*. (2021) showed that soluble sugar content of bulblets at 2 and 5^0c was significantly more than that of the control and 10^0c -treated bulblets. The lower the temperature, the faster the conversion of soluble sugars, and greater the soluble sugar content. Very minimum percentage of botrytis blight disease (only 1.0%) occurred in plants produced by bulbs preserved at 2.1-2.5^{0}c, while 26.45% and 78.95% disease occurred in plants from bulbs preserved in storage temperature of 6.5-7.5^{0}c and 8.0-10.0^{0}c, respectively.

Bulbs preserved in various media showed significant influence on single bulb weight and bulblet weight/plant (Table 6). Bulbs preserved in sawdust produced heaviest bulbs and bulblets/plant (29.0g and 2.69g, respectively)

Combined effect of temperature and media on bulb and bulblet production

Non-significant variations were recorded by the combination of temperature and media during bulb preservation at storage on bulbs and bulblet production in the next season (Table 7). But bulbs preserved at cool temperature (2.1-2.5^{0}c) with various storing showed better performances on all parameters of bulb and bulblet production.

CONCLUSION

The cool temperature (2.1-2.5^{0}c) with sawdust media showed better performances for bulbs preservation. For producing flower, bulb and bulblet production in next flowering season from bulbs kept at storage, cool temperature (2.1-2.5^{0}c) performed very well. As preservative media did not show any

Table 6: Performance of bulb production of flowers from stored bulb in relation to temperature and media

Treatment	Bulbs/ plant	Single bulb weight (g)	Bulb diameter (cm)	Bulblet number/ plant	Bulblet weight/ plant	Disease incidence (%)
Temperature						
2.1-2.5^{0}c (T_1)	1.98 a	29.94 a	4.93 a	2.45 a	2.79 a	1.0 c (4.86)
6.5-7.5^{0}c (T_2)	0.96 b	26.30 b	4.48 b	1.96 b	2.14 b	26.45 b (29.82)
8.0-10.0^{0}c (T_3)	0.92 b	23.83 c	4.27 b	1.85 b	2.09 b	78.95 a (60.97)
Level of significance	**	**	**	**	**	**
Media						
Sawdust (M_1)	1.38	28.56 a	4.71	2.22	2.59 a	32.82 (29.85)
Cocodust (M_2)	1.22	25.19 b	4.27	1.84	2.04 b	38.82 (34.60)
50% sawdust+50% cocodust (M_3)	1.28	26.15 b	4.50	2.10	2.26 ab	34.77 (31.20)
Level of significance	NS	**	NS	NS	*	NS
CV(%)	15.07	5.5	8.0	14.50	16.21	12.53

Figures in parentheses are transformed value
Means with the same letter(s) are not significantly different
**, significant at 1%; *, significant at 5%
NS, Non-significant

Table 7: Performance of bulb production of lilium flower from bulb kept in storage in relation to the combination of temperature and media

Treatment	Bulbs/ plant	Bulb weight (g)	Bulb diameter (cm)	Bulblet number/ plant	Bulblet weight/ plant	Disease incidence (%)
T_1 M_1	2.09	33.69	5.19	2.52	3.04	0.0 (3.91)
T_1 M_2	1.87	27.71	4.71	2.33	2.50	2.0 (6.76)
T_1 M_3	1.97	28.33	4.81	2.40	2.74	0.0 (3.91)
T_2 M_1	1.05	26.82	4.43	2.03	2.23	25.74 (29.37)
T_2 M_2	0.90	25.07	4.22	1.80	1.93	27.78 (30.62)
T_2 M_3	0.97	26.72	4.37	1.98	2.08	25.83 (29.46)
T_3 M_1	1.0	25.17	4.52	2.10	2.50	72.22 (56.26)
T_3 M_2	0.88	22.78	3.87	1.39	1.70	86.67 (66.42)
T_3 M_3	0.92	23.41	4.32	1.94	1.95	77.96 (60.24)
Level of significance	NS	NS	NS	NS	NS	NS
CV(%)	15.07	5.5	8.0	14.50	16.21	12.53

Figures in parentheses are transformed value
NS, non-significant
where, T1, 2.1-2.50c M1, sawdust (100%)
T2, 6.5-7.50c M2, cocodust (100%)
T3, 8.0-10.00c M3, sawdust+cocodust (50:50)

significant differences on various growth, flowering, bulb and bulblet production in next flowering season from stored bulbs without few exceptions. So, lilium bulbs can be successfully preserved at cool temperature (2.1-2.5^{0}c) with any media like sawdust (100%), cocodust (100%) and mixture (50:50) of sawdust and cocodust for producing quality flowers, bulbs and bulblet.

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Morphological and biochemical changes in avocado (*Persea americana*) during ripening

P C Tripathi, Anuradha Sane, A Shamina, S.Sriram and Nesara Begane

ICAR-Indian Institute of Horticultural Research, Bengaluru 560 089, Karnataka, India

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ABSTRACT

A study was carried out on the morphological and physiological changes in avocado during ripening at ICAR-IIHR, Bengaluru. A promising genotype (IC-0626510) having a large sized green fruits with yield potential of 281 fruits/year was used. Increased weight loss was induced at different stages of ripening from maturity to ripening showing weight loss (11.13% on 8th day) without any change in size of the fruit (9.15 cm x 8.23 cm). At ripening mean pulp recovery >75%, TSS 4.42 °Brix, 38.5%fat, 79.9% moisture, 30g/100g carbohydrate, 4.4% protein and 22.6% fibre was recorded. However firmness of fruits reduced considerably without change in fruit (light green) and pulp colour (creamy-white). There was no incidence of anthracnose on fruits throughout the period of study indicating that fruits of promising genotype are tolerant to anthracnose disease.

Key Words: Fat content, Fruit quality, Promising genotype, Weight loss

Avocado (*Persea Americana* Mill) is a native of tropical America. It is found growing in home gardens of several states of country. Almost each house is maintaining a few plants of avocado (Chithiraichelvan *et al*., 2002; Tripathi *et al*., 2014, Tripathi *et a.l*, 2016). The avocados are better stored at relative humidity 90 % - 95 % and temperature 12-13 oC. Grading can be done based on size: small (250 gm), medium (500 gm) and large (1000 gm) for internal and for export markets. Unripe avocados can be stored up to four weeks at 5.5 to 8 °C. Therefore, an experiment was conducted to study its morphological and physiological changes during ripening.

MATERIALS AND METHODS

The experiment was conducted at ICAR-IIHR, Bengaluru, during 2021-22. A promising seedling selection (IC-0626510) was used. The seedlings were raised and planted at IIHR FGB in 2013. Twenty fruits were collected from elite avocado tree. Fruits were harvested at physiological maturity. Data were recorded on variables, viz, fruit length (cm), breadth (cm), weight (g), pulp weight (g), pulp recovery (%), seed weight (g), rind weight (g) rind thickness (mm), cavity length (cm), and cavity diameter (cm). Fruit skin colour, pulp colour were determined using RHS colour chart. Fruit length and width were measured for using a Vernier calipers. Fruit skin colour changes were evaluated every day using RHS colour chart. Weight loss was measured on 10 fruits every day during 8 days with an electronic scale balance (0.1-1500 g). The fat, moisture, carbohydrate, protein and fibre content were estimated using standard procedures. Pulp firmness of five fruits was determined manually by 0-10 scale. Additionally, descriptive analysis was performed using MS excel.

RESULTS AND DISCUSSION

The fruit evaluation for fruit weight, fruit size, fruit and pulp colour, fruit firmness and seed colour were evaluated from harvesting at full maturity till ripening when fruit reached a soft texture and ripen properly for consumption. The data revealed fruit weight loss was 1.24 % day 1 and weight loss gradually increased till it reached full ripe stage (Table1). At 8 DAH fruit weight loss was 11.13%. The fruit length and breadth remained constant without any change from maturity till ripening. The firmness of fruits showed differences during ripening process. The fruits showed a significant reduction in firmness at 8 days after harvesting (DAH) with average value of 2 (1-10 scale). At 8 DAH, all fruits showed similar firmness (Table 1). The fruit skin color showed no differences during ripening process (144 A Yellow

***Corresponding author :** prakash.Tripathi@icar.gov.in

green group at harvesting), that remained the same at 8 DAH. The pulp colour was yellow (3 C ;yellow group) that remained same at 8 DAH. Similarly seed colour is greyed orange (164 A + 164 C; greyed orange group) did not undergo change during ripening.

At ripening mean fruit length was 9.15 cm and mean fruit diameter was 8.23 cm with pulp recovery >75%. Mean seed weight was 71 g with TSS 4.42 °Brix. Fruit color is light green and flesh color is creamy white. It is late bearing genotype with pear shaped fruits and fruit is thin skinned (10mm) (Table 2). Fruit shape is obovate, dark green colour with creamish white flesh colour. It is suitable for fresh fruit purpose.

Ripe fruits were analyzed for biochemical parameters (Table 2). The moisture content of avocado pulp was 79.9 %. The fat content ranged from 36.28 - 40.21%. Mean values for carbohydrate, protein were 30.12 g/100g and 4.38% respectively. Crude fibre content accounted for 22.63%.

The weight loss was gradual from maturity to ripening. Adato and Gazit (1974) mentioned that avocado fruits ripen faster when weight loss is higher; this loss of water is considered the main cause of physical deterioration of fruit quality (Kader,2002). The avocado is considered a climacteric fruit (Bower and Cutting 1988; Osuna-García *et al*., 2005). Though color and firmness changes are indicative of a ripening process, in our study only changes were observed on firmness and not in fruit colour. Cox *et al.* (2004) reported changes occurred in colour and firmness. Colour alteration of exocarp are result of changes in structure and conformation of thylakoids (Navarro *et al*., 1999; Bonfiglioli *et al*., 1994) so, these alterations affect the chlorophyll content in cell, resulting in development of yellowish-white colour symptoms, than later turn into purple and reddish color due to the increase in anthocyanin content (Cox *et al*. 2004; Vallejo-Pérez *et al*., 2014). The average size of fruit (9.15cm × 8.23 cm) similar without any reduction. However Vallejo-Perez (2015) reported 7-9 % in size reduction.

Saucedo-Carabez *et al.* (2013) also reported yield reduction of 52 -75 % from symptomatic B Hass^ avocado trees. This response is probably due to deterioration of phloem and xylem tissues causes

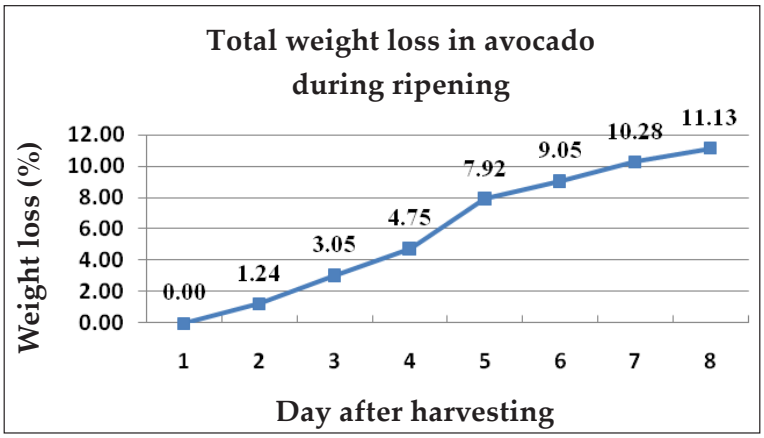

Fig. 1: Weight loss in avocado fruit during ripening

Table 1. Changes in morphological parameters of avocado during ripening

Parameter	Day after storage							
	1	2	3	4	5	6	7	8
Weight loss (%)	0.00	1.24	3.05	4.75	7.92	9.05	10.28	11.13
Fruit length (cm)	10.85	10.85	10.85	10.85	10.85	10.85	10.85	10.85
Fruit diameter(cm)	8.66	8.66	8.66	8.66	8.66	8.66	8.66	8.66
Fruit colour	144 A	144 A	144 A	144 A	144 A	144 A	144 A	144 A
Pulp colour	3 C	3 C	3 C	3 C	3 C	3 C	3 C	3 C
Firmness(scale)	10	10	9	8	6	5	3	2

Fruit colour- 144 A Yellow green group
Pulp colour -3 C (Yellow group)
Seed colour: 164 A + 164 C (Greyed orange group)

Table 2. Biochemical parameters in avocado mature fruit

	Fat (%)	Moisture (%)	Carbohydrate (g/100g)	Protein (%)	Crude fiber (%)
Mean	38.49	79.9	30.12	4.38	22.63
Minimum	36.28	78.03	27.31	4.19	21.013
Maximum	40.21	81.81	32.51	4.56	24.26
Standard error	0.86	0.57	1.083	0.19	1.62
Standard deviation	1.73	1.40	2.167	0.27	2.29
CV (%)	4.48	1.75	7.195	7.19	10.13

by ASBVd (Vallejo-Pérez *et al*. 2014). Avocados have the highest energy value (245 cal/100 g) of any fruit besides being a reservoir of several vitamins and minerals (Tripathi *et al*., 2022). The protein content is 4.38% and fat is 39%. According to Tripathi *et al*. (2022) that the pulp is rich in proteins (up to 4%) and fat (up to 30%), but low in carbohydrates. The fat is similar to olive oil in composition and is widely employed in the preparation of cosmetics as they work well on skin ailments.

According to Mazumdar, (2004) fruits contain less than one per cent sugar and good for diabetics. Dietary fibre which is important in keeping gut health was found to be high in avocado. In adults, emerging evidence suggests that higher daily intake of fiber-rich fruit and vegetable servings is associated with lower incidences of anxiety, greater happiness, higher life satisfaction, and greater social-emotional well-being. Increased fruit fiber such as pectin intake has been suggested to correct gastrointestinal abnormality and promote microbial health to potentially enhance gut-brain communication (Dreher. 2018)

CONCLUSION

There is very little change in weight loss and fruit quality in terms of appearance, size, quality and anthracnose. The selected genotype is promising and fulfils the minimum requirements of fresh market.

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Correlation studies in avocado (*Persea americana*) accessions for morphological and biochemical characters

B M Muralidhara[1&2], R Venugopalan[1], T Sakthivel[1], G Karunakaran[1], M K Honnabyraiah[2] and Siddanna Savadi[3]

[1&2] *ICAR-Indian Institute of Horticultural Research, Hesaraghatta, Lake Post, Bengaluru-560 089, Karnataka, India*
[2]*College of Horticulture, Bengaluru, University of Horticultural Sciences, Bagalkote- 587 104, Karnataka, India*
[3]*ICAR-Directorate of Cashew Research, Puttur - 574 202, Karnataka, India*
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ABSTRACT

The correlation coefficients were estimated for different morphological and biochemical traits in 83 avocado (*Persea americana* Mill.) accessions of South India. The fruit weight, fruit length, fruit width, pulp weight and seed weight showed highly significant positive correlations with fruit yield, while peel per cent showed negative correlation with fruit yield. These traits can be utilized for selection of high-yielding genotypes. The total phenols content has positive correlation with DPPH antioxidant activity. The dry-matter content of pulp showed highly significant positive correlation with oil content of fresh and dry pulp, while moisture content in pulp showed negative correlation with oil content of fresh pulp. The dry-matter content and moisture content of pulp can be utilized for selection of high oil-yielding accessions.

Key Words: Oil content, Selection, Correlation, Dry-matter, FRAP

Avocado (*Persea americana* Mill.) belonging to Lauraceae family commercially grown in more than 80 countries (FAO STAT, 2019). It is a rich source of several bioactive compounds (Gomez-Caravaca *et al*., 2015 and Salazar-Lopez *et al*., 2020). The broader genetic base for leaf shape, fruit shape, peel colour, pulp colour, peel thickness and seed shapes is available in India due to seeds propagation from many decades (Tripathi *et al*., 2022). To build up a viable breeding programme, knowledge of interrelationships between yield and yield contributing characteristics is required. Hence, selection of genotypes directly based on yield may not be realistic and it depends on several other contributing components. Simple correlation analysis enables indirect selection of required trait (Robinson *et al*., 1951). Hence present study was formulated to know direct and indirect relationship between different morphological and biochemical characters of avocado.

MATERIALS AND METHODS

The study was carried out at ICAR-Indian Institute of Horticultural Research, Bengaluru, during 2018-19 and 2019-20. Eight-three accessions collected from different parts of South India were characterized for quantitative characters, viz. fruit length (cm), fruit width (cm), fruit weight (g), pulp weight (g), pulp per cent, seed weight (g), seed per cent, peel weight (g), peel per cent, length of seed cavity (cm), width of seed cavity (cm), seed length (cm), seed width (cm), leaf length (cm), leaf width (cm), pedicel diameter (cm), peel thickness (mm) and yield per tree. The biochemical characters, such as CUPRAC (Cupric Reducing Antioxidant Capacity) activity, FRAP (ferric reducing antioxidant power) activity, DPPH (2,2-diphenyl- 1-picrylhydrazyl) activity, total phenols, total carotenoids (mg /100g), TSS (total soluble solids) (° Brix), moisture content (%), dry-matter content (%), oil content in dry pulp (%), oil content in fresh pulp (%) and crude fiber (%) were also studied. The mean values were used for correlation studies. Correlations between morphological and biochemical traits were analyzed using the Pearson correlation coefficients by SPSS 16.0 software.

***Corresponding author :** murlidhara.m@icar.gov.in

RESULTS AND DISCUSSION

The fruit length showed highly significant positive correlation with fruit width (0.38), fruit weight (0.72), pulp weight (0.75), pulp per cent (0.56), peel weight (0.48), length of seed cavity (0.78), seed length (0.67) and yield (0.36/tree), showiing negative correlation with seed percent (-0.42) and peel percent (-0.46) (Table 1.). The accessions having more fruit

Table 1: Correlation coefficients for morphological characters of avocado accessions

Trait	FL	FW	FWT	PLW	PLP	SWT	SP	PEWT	PEP	LSC	WSC	SL	SW	LL	LW	PDD	PET	YEL
FL	1																	
FW	0.38***	1																
FWT	0.72***	0.83***	1															
PLW	0.75***	0.79***	0.98***	1														
PPT	0.56***	0.35**	0.52***	0.64***	1													
SWT	0.31**	0.65***	0.64***	0.51***	-0.23*	1												
SPT	-0.42***	-0.22*	-0.36***	-0.50***	-0.92***	0.44***	1											
PEWT	0.48***	0.73***	0.77***	0.72***	0.25*	0.48***	-0.32**	1										
PEPT	-0.46***	-0.40***	-0.50***	-0.52***	-0.46***	-0.41***	0.08	0.08	1									
LSC	0.78***	0.29**	0.60***	0.59***	0.24*	0.45***	-0.06	0.32**	-0.46***	1								
WSC	0.20	0.72***	0.61***	0.48***	-0.20	0.91***	0.38***	0.50***	-0.35**	0.42***	1							
SL	0.67***	0.35**	0.57***	0.51***	0.07	0.61***	0.11	0.33**	-0.44***	0.76***	0.51***	1						
SW	0.17	0.65***	0.55***	0.42***	-0.28*	0.96***	0.45***	0.48***	-0.32**	0.34**	0.93***	0.51***	1					
LL	0.10	-0.07	-0.01	-0.03	-0.08	0.08	0.10	-0.03	-0.007	0.154	0.08	0.01	0.02	1				
LW	0.20	-0.05	0.09	0.05	-0.12	0.20	0.16	0.05	-0.06	0.26*	0.15	0.25*	0.15	0.65***	1			
PDD	0.15	0.43***	0.38***	0.38***	0.20	0.14	-0.25*	0.50***	0.05	-0.05	0.13	0.01	0.11	-0.05	-0.17	1		
PET	-0.26*	0.13	-0.04	-0.10	-0.19	0.11	0.09	0.24*	0.28**	-0.37***	0.09	-0.21	0.11	-0.09	-0.20	0.36***	1	
YEL	0.36***	0.35**	0.38***	0.35**	0.12	0.33**	-0.03	0.26*	-0.25*	0.28*	0.25*	0.30**	0.20	0.10	0.01	0.16	-0.01	1

*** Significant at 0.001 level; ** 0.01 level; * 0.05 level

FL: Fruit length; FW: Fruit width; FWT: Fruit weight; PLW: Pulp weight; PLP: Pulp per cent; SW: Seed weight; SP: Seed per cent; PLWT: Peel weight; PEP: Peel per cent; LSC: Length of seed cavity; WSC: Width of seed cavity; SL: Seed length; SW: Seed width; LL: Leaf length; LW: Leaf width; PDD: Pedicel diameter; PET: Peel thickness; YLD: Yield per tree

length might have more pulp weight, pulp percentage and less seed percentage. The similar findings were reported by Srivastava *et al*. (2023), Rathor (2005), Kumar *et al*. (2006) and Patel *et al*. (2017). Simi (2006) reported positive correlation of fruit length with fruit weight and diameter of mango. Fruit width exhibited positive direct effect on fruit weight (0.83), pulp weight (0.79), seed weight (0.64), peel weight (0.73), width of seed cavity (0.72), seed width (0.65) and pedicel diameter (0.43), showing negative correlation with seed per cent (-0.22) and peel per cent (-0.40).

Fruit weight showed highly positive correlation with pulp weight (0.98), pulp per cent (0.52), seed weight (0.64), peel weight (0.77), seed length, seed width, length and width of seed cavity but had negative correlation with seed per cent (-0.36) and peel per cent (-0.50). Pulp weight expressed significant positive correlation with pulp per cent (0.64) but had negative correlation with seed (-0.50) and peel (-0.52) per cent. Pulp percent showed negative effect on seed per cent and peel per cent of fruit. Seed weight positively correlated with seed percent (0.44), peel weight (0.48) but had negative correlation with peel per cent (-0.41).

Seed per cent and peel weight showed highly significant correlation. Peel per cent reported negative correlation with seed and seed cavity characters. Positive and significant correlation was recorded for seed length and seed cavity characters, seed length and seed width, leaf length and leaf width, pedicel diameter and peel thickness. Positive correlation of seed length and length seed cavity (0.521), seed circumference and length of seed cavity (0.496) was reported by Gopi *et al.* (2021) which is in agreement with the present study. The fruit weight, fruit length, fruit width, pulp weight and seed weight showed highly significant correlation effect on yield of the plant while peel percent showed negative correlation on yield which indicates higher the fruit and seed weight more will be the yield (Table 1).

The CUPPRAC antioxidant activity showed highly and positive relationship with FRAP activity (0.40) and positive relationship with oil content in fresh pulp (0.35) and dry-matter content of pulp (0.33), whereas negatively correlated with moisture content (-0.33) (Table 2.). The similar positive correlation was reported for total phenols and antioxidants activity by Wang *et al*. (2010); Muralidhara *et al*. (2019), Muralidhara *et al*. (2020) and Lal et *al*. (2023). Total phenols had positive correlation with DPPH activity (0.80) and FRAP

Table 2: Correlation matrix for biochemical characters of avocado

Trait	CUPRAC activity	FRAP activity	DPPH activity	Total phenols	TSS	Total carotenoids	Oil content (dry weight)	Moisture content	Oil content (fresh weight)	Dry matter	Crude fibre
CUPRAC activity	1										
FRAP activity	0.40***	1									
DPPH activity	0.17	0.24*	1								
Total phenols	0.02	0.14	0.80***	1							
TSS (ºB)	0.09	0.024	0.22*	0.21	1						
Total carotenoids	0.13	0.45***	0.13	0.07	0.21	1					
Oil content (Dry weight)	0.22*	-0.10	0.093	0.15	0.14	0.18	1				
Moisture content	-0.33**	-0.08	0.051	0.04	-0.30**	-0.27*	-0.65***	1			
Oil content (Fry weight)	0.35**	0.016	-0.004	0.03	0.25*	0.24*	0.85***	-0.95***	1		
Dry matter	0.33**	0.08	-0.05	-0.04	0.30**	0.27*	0.65***	-1***	0.95***	1	
Crude fibre	-0.01	-0.13	-0.11	-0.05	0.01	0.12	0.21	-0.06	0.14	0.06	1

*** Significant at 0.001 level; **0.01 level; *0.05 level

activity expressed highly significant correlation with total carotenoids content. Veena *et al*. (2019) reported that total phenols had a significant positive correlation with total antioxidants (0.68).

Total carotenoids also had positive correlation with oil content in fresh pulp (0.24) and dry-matter content of pulp (0.27) and negatively correlation with moisture content (-0.27). This will help to identify high oil content accessions based on dry-matter content. Dry-matter content of pulp had highly positive correlation with oil content of dry (0.65) and fresh pulp (0.95) (Table 2). Lu *et al*. (2009) and Carvalho *et al*. (2015) reported dry-matter and carotenoids content had positive relationship with fatty acid content. The negative correlation between oil content and moisture content in different varieties of avocado were also reported by Bezuidenhout and Bezuidenhout (2014). Carvalho *et al.* (2015) reported positive correlation of oil content with dry matter content of pulp in avocado.

CONCLUSION

The fruit weight, fruit length, fruit width, pulp weight and seed weight showed highly significant positive correlation with fruit yield and can be utilized for selection of high-yielding genotypes. The dry-matter content of pulp showed highly significant positive correlation with oil content of fresh and dry pulp whereas moisture contentment showed negative correlation with oil content of fresh pulp. The dry-matter and moisture content of pulp can be utilized for selection of high oil yielding accessions.

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Morphological and physiological responses of CMD resistant cassava (*Manihot esculenta*) genotypes to nutrient regimes

S Sunitha*, M N Sheela, J Suresh Kumar and T Makeshkumar

ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

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ABSTRACT

The field studies were carried out on cassava (*Manihot esculenta* Crantz) varieties resistant to cassava mosaic disease (V_1-CR43-2, V_2-15 S 59, V_3-15 S 409 , V_4-15 S 154, V_5-CR43-7, V_6-8S 501-2, V_7-CR24-4, V_8- 15S-436) and three levels of nutrient doses (F_1-75:50:75, F_2- 100:50:100 and F_3- 125:50:125 kg NPK/ha) in spilt plot design during 2018-19 and 2019-20 to assess the response of varieties to nutrition. There was significant difference in morphological and physiological parameters among varieties, but not with different nutrient doses. The rate of leaf production was more 4-6 months after planting (34-40%) and percentage retention was less for first season crop (55.6-41.4%) compared to second season (77.2-52.5 %). Though not significant, higher nutrition levels recorded more number of green leaves as well as leaf area at most of the stages. Tuber bulking rate was 0.19 - 0.37 g/day during initial two months. The rate increased and maximum bulking was recorded between 4 and 8 months (2.15-6.71 g/day). Pooled analysis also showed a gradual increase in tuber yield with nutrient levels, but was not significant (7%). The varieties responded differently to nutrients with respect to tuber yield. F_3 recorded higher tuber yield (66.9 t/ha) than F_1 (45.7 t/ha) in V_7 and V_6 recorded highest tuber yield with F_2 level of nutrition (71.1 t/ha). F_1 was found optimum for rest of the varieties.

Key Words: Leaf area index, Nutrition, Tuber bulking rate, Tuber yield, Varietal response

Cassava (*Manihot esculenta* Crantz) is the fourth most important food crop in the world. Its wide adaptability to various cropping and farming systems, high yield potential, and season insensitivity ensuring year-round availability, make it an ideal food security crop and versatile industrial raw material. Cassava is considered as a low-input crop, able to yield reasonably good under adverse environments with low fertility and acidic soils where other crops fail (El-Sharkawy *et al*., 2012). However, adequate supply of nitrogen and potassium is essential for high productivity and yield stability in cassava (Ezui *et al*., 2017). The total N, P and K uptake requirements for producing one ton of fresh cassava tuber ranged from 2.9 to 6.9 kg for N, 0.68 to 1.3 kg for P and 3.9 to 7.9 kg for K (Byju and Suja, 2020). Cassava mosaic disease (CMD) is prevalent in India, Africa and Sri Lanka. Different CMD resistant varieties were assessed for their morphological and physiological traits under different nutrient regimes and its relation to final tuber yield.

***Corresponding author :** sunitharajan1@rediffmail.com

MATERIALS AND METHODS

Field experiments were conducted during 2018-19 and 2019-20 at ICAR-CTCRI, Thiruvananthapuram, Kerala. The soil is deep, well-drained, sandy clay loam, moderately acidic. Split-plot design in a completely randomized block was used. All CMD resistant varieties were allocated to the main plots (V_1- Sree Sakthi, V_2-15 S 59, V_3-15 S 409, V_4-15 S 154, V_5-CR43-7, V_6- Sree Kaveri, V_7- Sree Reksha, V_8- 15S-436) and three fertilizer doses were allocated to sub-plots (F_1-75:50:75, F_2- 100:50:100 (present recommendation) and F_3- 125:50:125 NPK/ha). The crop was planted uniformly at a spacing of 90 cm × 90 cm with a gross plot size of 36 plants and a net plot size of 16 plants. The farmyard manure @ 12.5 t/ha and full dose of phosphorus were applied as basal. The N and K were applied in two equal splits, half as basal at planting and the rest half, 45 days after planting.

The morphological data on height, number of green and fallen leaves, leaf retention rate and leaf area were recorded at two months intervals. Destructive sampling was done to assess the biomass production and partitioning at two months intervals. Physiological

parameters, viz. leaf area index (LAI), total dry-matter production (TDMP), tuber bulking rate (TBR), crop growth rate (CGR), relative growth rate (RGR), leaf area ratio (LAR), leaf area duration (LAD) and harvest index(HI) (Pandey *et al*., 2017) and finally the yield were estimated. All the data collected were analysed statistically for individual years and pooled.

RESULTS AND DISCUSSION

During first season, height of plants varied significantly at 2 MAP, and also towards later stages after six months. V_8 recorded lowest values at all the stages. Though not statistically significant, F_2 level of fertilization resulted in taller plants. During second season, difference in height of plants could be noted only after six months, V_1, V_3, V_5, V_6 and V_7 were comparatively taller. The rate of increase in height was more during 2-8 MAP during the first season, whereas during second season, rate was more from 4 months.

The total leaf production was highest in V_2 during both the seasons. Total leaf production varied from 99.18 in V_7 to 151.11 in V_2 during first season (NS) and 171.22 in V_7 to 331.25 in V_2 during second season (p=0.05; LSD: 84.26). The rate of leaf production was more from 2-4 MAP (34%) and from 4-6 MAP (40%) during first and second seasons respectively. Though the effect was not significant, more number of leaves was produced under F_2 and F_3 level of nutrition. Rate of leaf retention was more during initial stages and gradually reduced towards maturity.

Percentage retention was less for first season crop and it varied from 55.6 to 41.4%. The value increased at 8 MAP due to rains received. Rate of leaf retention varied from 77.2 to 52.5 % during second season. Percentage of leaf retention was maximum for V_2 at all the stages during 2018-19 (45.96%). However, during 2019-20, it varied among varieties at different phases of growth, but values were higher compared to first season at all stages. Second crop retained 77.7 % leaves after 4 MAP and 64.2% after 6 MAP, but for first crop, retention percentage was less than 50% from 4 MAP. Consequently, number of green leaves was more during second season, compared to first season. Green leaves were highest for V_2 from 4-10 MAP during first season, while during second season, V_1, V_2, V_4, V_6 and V_8 had more number of green leaves after 4 MAP and all values were on a par.

Higher nutrition levels recorded more number of green leaves as well as leaf area at most of the stages. The leaf area differed significantly among varieties at 2 MAP (p=0.05; LSD: 2.02) and 10 MAP (p=0.05; LSD: 6.76) during first season. The value was maximum for V_6 at 2, 4,6 and 8 MAP and V_1 recorded maximum value at 10 MAP. During second season also V_6 recorded maximum leaf area at 2, 4 and 6 MAP, thereafter, V_8 recorded the maximum at 8 and 10 MAP and values statistically varied towards later stages.

Though cassava is grown mostly under rainfed conditions, supplementary irrigations during drought period could give higher dry-matter production, crop growth rate (CGR), tuber weight and yield (Sunitha *et al*., 2013; Sunitha *et al*.,2016). Cassava responds positively to management practices, it is sensitive to over fertilization, especially with N, which resulted in excessive leaf formation at the expense of root growth (Sagrilo *et al*., 2006). We also recorded more height, number of leaves and leaf area with higher nutrition, though difference was not significant. Dry period coincided with more leaf fall and less retention of green leaves and subsequent leaf area. Under water stress, cassava frequently sheds its leaves, resulting significantly in reduced productivity (El-Sharkawy, 2014; Daryanto *et al*., 2016).

All the growth indices were highly influenced by rainfall pattern received during both growing seasons. Leaf area index increased at a slow pace during establishment phase of initial 2 months in first season. It reached maximum at 4 months, and retained more or less the same value at 6 MAP, but decreased at 8 MAP, followed by a slight increase at 10 MAP during first season. This is mainly because of rains received during later stage, ie., after 8 months, which triggered out- flux of starch from tubers to vegetative parts. During second season, LAI development was slow up to 4 months, reached peak at 6 and 8 MAP, then declined.

During both seasons, leaf area indices were very much dependent on rainfall, temperature and leaf retention. Reduced leaf area represented dry periods of season, resulting in maximum leaf fall, thereby reducing the transpiration loss and above ground growth, which is a self-defending mechanism in cassava. The pattern of leaf area development was more or less similar with all fertilizer regimes, higher levels resulted in higher values, but variation was not significant. This is in agreement with Mwamba (2021) and Sunitha *et al*. (2018), where cassava recorded less LAI with dry periods and an increase with resumption of rains, but more or less uniformly with different fertilization regimes. A similar trend

was observed in harvest index values also which showed a decline from 6 MAP (0.55-0.71) to 10 MAP (0.53-0.65) during first season, but an increasing trend during second season (0.53-0.79).

The CGR expressed a steady increase from planting up to harvesting, during both seasons. Tuber development from 6 months at a faster rate caused a rapid increase in CGR from 6 MAP. The values ranged from 0.65 (V_8) to 2.83 g/day (V_3) during first two months and increased to 7.49 (V_2) to 21.56 g/day (V_1) from 8 to 10 months. Though vegetative growth was less, tuber development and maturity caused a significant increase in CGR towards later stages, after six months. However, relative growth rate (RGR) was comparatively higher during first two months in both seasons and the values ranged from 0.026 (V_8) to 0.037 g/g/ day (V_3). Leaf area duration expressed a progressive trend from planting to harvesting. The rate of increase was more from 6-8 MAP. Consequently leaf area ratio (LAR) showed a declining trend from planting to harvesting. The values ranged from 0.005 (V_3) to 0.014 (V_8) at 4 MAP and 0.0015 (V_3) to 0.0053 (V_8) at 10 MAP.

Tuber bulking rate was 0.19-0.37 g/day during initial two months as tuber initiation occurs only 40-45 days in cassava. Then rate increased and maximum bulking was recorded between 4 and 8 months (Fig.1). Once tuber bulking initiated, rate of increase in tuber dry- matter continued until, it is lower than other vegetative parts. This is mainly because, dry-matter accumulation in tubers occurs mainly by the translocation of starch assimilated from vegetative parts to storage roots and is not by formation of new tissues. This is in line with Adalton *et al.* (2017) which indicted that late application of potassium for second cycle growth of cassava encouraged fresh plant growth and storage yield.

Biomass partitioning at various stages of the crop was not affected by nutrient levels, but only with varieties, but in a similar trend. At 2 MAP, leaves and stem portion contributed a major share of biomass. Leaves accounted for 32.2% (V_3) to 63.6 % (V_6) of biomass in different varieties and stem accounted for 18.3 (V_6) to 56.1 % (V_2). Leaf biomass was reduced to 3.7-7.9% at 10 months, except in V_5 and V_8, where stem and leaves retained almost equal biomass, restricting the tuber biomass production after 8 months, as reported by Adalton *et al.* (2017). This is due to regrowth of stems and leaves at the expense of tubers with favourable soil moisture conditions.

A major share of the tuber bulking occurred between 4-8 MAP in all the varieties except V_8 in both the seasons, where tuber bulking was more during 6 to 8 MAP. There was a decrease in tuber biomass and increase in stem and leaf biomass during second season irrespective of the varieties. Intermittent rains received during summer season, just before harvesting triggered vegetative growth, even causing the reverse translocation of starch from tubers to vegetative parts because of excess soil moisture. During drought stress, LAI and dry matter partitioning to stems and leaves reduces rapidly as photo-assimilates are mostly channelled to growth of storage roots and only increase after resumption of rainfall as reported in some studies (Ezui *et al.*, 2015).

There was significant difference in tuber yield, only with varieties. During first season, a corresponding increase was noticed from F_1 to F_3, in second season the values were almost the same. Pooled analysis

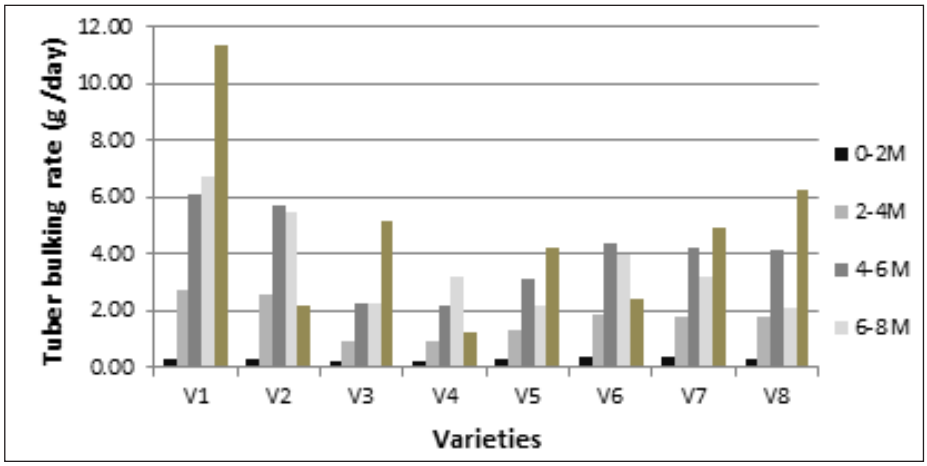

Fig. 1: Tuber bulking rate in different varieties from planting to harvesting (pooled means)

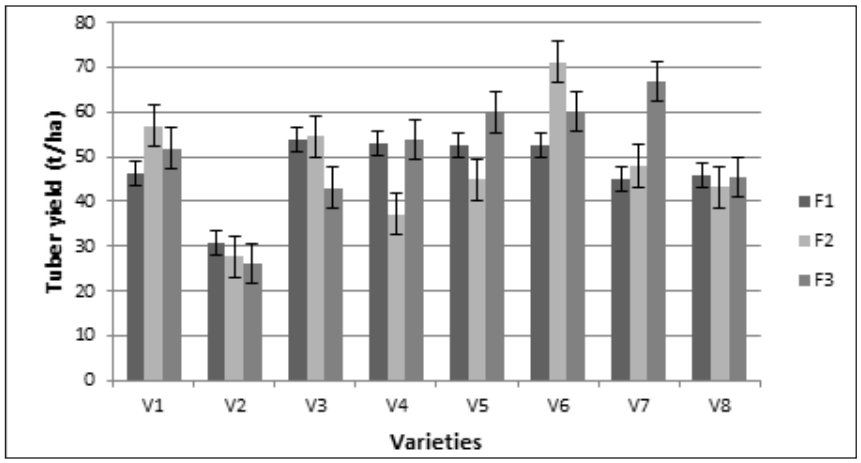

Fig. 2: Tuber yield of varieties under different nutrient doses (pooled means)

also showed a gradual increase in tuber yield with nutrient levels, but was not significant. F_3 level of nutrition resulted in only 7% increase in tuber yield compared to F_1 based on pooled data analysis and the variation was not significant. Variable response of varieties in growth and yield attributes is reported in cassava (Nedunchezhiyan *et al.,* 2022) and potato (Jatav *et al*., 2023).

The interaction effects were significant, ie., varieties responded differently to nutrients with respect to tuber yield. Higher level of nutrition, F_3 recorded significantly higher yield in V_7 in both seasons and pooled performance. V_6 recorded highest tuber yield with F_2 level of nutrition. Rest of the varieties did not express any significant variation in yield with nutrition, ie. a lower level of nutrition, F_1 is found optimum for these varieties (Fig.2). In earlier study (Mutchima, 2018), it was observed that cassava starch waste at 12.5 t and 75 kg of N or 25 t of cassava starch waste and 25 kg N resulted in more harvest index and storage root yield in cassava compared to other higher levels of nutrition. It could be inferred that these treatments supplied a good balance between total production of carbohydrates by the plants and their distribution to the roots as reported in cassava through fertigation (Sunitha *et al.,* 2013; Sunitha *et al*., 2018).

Significant variation was noted in tuber yield among varieties and in among seasons. First season crop which experienced a dry period during critical growth stage suffered yield loss compared to second season (61%). The first 3–5 MAP is a critical period for cassava (Turyagyenda *et al*., 2013; Sunitha *et al*., 2017). Moisture stress, during these first months of leaf formation, root initiation, and tuberization can reduce the yield of storage root by up to 60%.

A 30% yield reduction of cassava cultivated in Kerala was observed due to late monsoons and planting followed by a period of drought. The study emphasized the need for timely planting of cassava, coinciding with initiation of monsoon season so that crop will get enough soil moisture during establishment and tuber bulking stages with subsequent monsoon rains or else need for supplementary irrigation to realise maximum tuber yield. Also the possibility of reducing fertilizer doses by 25% in medium fertile soils.

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Effect of light-emitting diodes on somatic embryogenesis and tissue-cultured plantlet growth of arecanut (*Areca catechu*) dwarf hybrid VTLAH-2

Aparna Veluru*, K. Devakumar[1], M. Neema, Sandip Shil[2], N.R. Nagaraja[3], and Anitha Karun

ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala, 671 124, India
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ABSTRACT

This study was carried out to evaluate the effects of LEDs on embryogenic callus proliferation, somatic embryo formation and tissue cultured plantlet growth of arecanut (*Areca catechu* L.) dwarf hybrid (VTLAH-2) at ICAR-CPCRI, Kasaragod, Kerala, during 2021-2022. Yellow, red, blue, white monochromatic LEDs, and a combination of red: blue and blue: yellow with different photosynthetic photon flux densities (PPFDs 10, 20 and 100 μmol $m^{-2}s^{-1}$) were used. Eeuwen's Y3 basal media supplemented with picloram 2.5 μM were used for multiplication of calli. Embryogenic calli were inoculated to multiplication media, and these plates were kept under different LED conditions to examine calli multiplication and somatic embryogenesis. To check the growth of plantlets, germinated somatic embryos were transferred to test tubes containing arecanut plantlet growing media (i.e., 0.5 mg/L BAP +0.5 mg/L NAA and +0.25 mg/L IBA with Y3 basal medium. Multiplication rate of arecanut embryogenic calli (0.051±0.008 $gg^{-1}d^{-1}$), somatic embryo formation (46.1±2.9), plantlet growth (RGR-wt.0.9±0.07 $gg^{-1}d^{-1}$; RGR-ht: 0.57±0.01 $cm.cm^{-1}d^{-1}$) and survival (61.4±4.3%) were found to be superior under a combination of red-yellow LED, which was followed by blue and yellow monochromatic LEDs. Whereas comparatively lower callus multiplication (0.008±0.001 $gg^{-1}d^{-1}$) and plantlet growth (RGR-wt: 0.72±0.03 $gg^{-1}d^{-1}$; RGR-ht: 0.24±0.12 $cm.cm^{-1}d^{-1}$) was noticed with white and red LEDs with a PPFD values of 100 μmol $m^{-2}s^{-1}$ and 20 μmol $m^{-2}s^{-1}$ consecutively. Thus, there was a positive effect of LED light source on arecanut somatic embryogenesis and plantlet growth.

Key Words: LED, Somatic embryogenesis, Callus multiplication, *In vitro* plantlet growth

Arecanut (*Areca catechu* L.) belong to the family Arecaceae. Traditionally, its seed is the only available propagules like other palm species. Tissue culture seems to be the only available vegetative propagation method applicable to this palm. Use of tissue culture technology for clonal multiplication of arecanut has been reported (Karun *et al*., 2004). However, in dwarfs and dwarf hybrid arecanut material the cultures have showed lower multiplication rate and prolonged regeneration cycle for plantlet development. Light, one of the key environmental factors, work as a signal and energy source, affects almost every aspect of plant life (Reuveni and Evenor, 2007; OuYang *et al*., 2015). As an alternative to the conventional sources of light, light-emitting diodes (LEDs) have emerged in recent years (Río-Álvarez *et al*., 2014). Moreover, LEDs emit wavelengths that are consistent with the absorption spectra of different plant species and can promote the growth effectively (Li *et al*., 2018). LEDs of different wavelengths can be used independently or in combinations to optimize the growth of plant cultures (Shengxin *et al*., 2016). Under *in vitro* conditions, lower light intensities are sufficient to regulate plant morphogenesis due to availability of sugar in medium which acts as a source of energy. Also, energy consumption levels of *in vitro* cultured plants are low, and they do not overheat due to maintenance of humidity in closed vessels (George and Davies, 2008). The PPFD requirement for *in vitro* grown plants varies, and PPFD range for herbaceous plants varies from 7 to 120 μmol m^{-2} s^{-1}, but for majority species optimal level is at 30-40 μmol m^{-2} s^{-1} (Alvarenga *et al*., 2015; Silva *et al*., 2017). LEDs with different wavelengths (colours) and intensities can be used to improve *in vitro* multiplication of tissue-cultured plants. A combination of red and blue LEDs (4:1) improved shoot multiplication (He *et al*., 2020). Use of a combination of red (70%) and blue (30%) LEDs (40-120 μ mol m^{-2} s^{-1}) improved shoot multiplication in gerbera, sugarcane, and rice under

***Corresponding author :** aparna.cpcri@ gmail.com

[1]ICAR-Sugarcane Breeding Institute, Coimbatore, 641 007, India

[2]ICAR- CPCRI, Research Centre, Mohitnagar, West Bengal

[3]ICAR-CPCRI, Regional Station, Vittal, Karnataka

in vitro (Cioc *et al*., 2019; Silva *et al*., 2014; YU Lan-lan *et al*., 2020). However, the best LED light source for palm tissue culture remains unknown. Therefore, monochromatic LEDs (white, red, blue, yellow) and their combinations (red: blue 1:1; red: yellow 1:1) with different PPFD values (10, 20 and 100 μmol m^{-2} s^{-1}) were used to study their influence on embryogenic callus multiplication, somatic embryogenesis, and tissue-cultured plantlet growth of arecanut.

MATERIALS AND METHODS

Embryogenic calli and germinated somatic embryos of *Areca catechu* dwarf hybrid VTLAH-2 were selected. The 0.5 g callus was weighed and incubated in callus multiplication media in a Petri plate containing Eeuwen's Y3 solid medium (pH 5.8) supplemented with 2.5 μM picloram. These plates were subjected to LED lights for observations on the multiplication and somatic embryo formation (formation of somatic embryos were observed on same multiplication media). Sub-culturing of multiplied material was carried out at monthly interval to the same multiplication media and somatic embryos formed were transferred to hormone free Y3 media (Aparna *et al*., 2022, Neema *et al*., 2022) for its growth and development. The observations on callus growth, other callus parameters and somatic embryo formation were recorded.

For checking the influence of LEDs on somatic embryo growth and plantlet development, germinated somatic embryos having a size of 0.8-1.0 cm were transferred to test tubes having Eeuwen'sY3 basal media supplemented with 0.5 mg/L BA, 0.5 mg/L NAA and 0.25 mg/L of IBA (pH 5.8) (Aparna *et al*., 2022). The selected somatic embryos were individually transferred to test tubes and were exposed to different LED light conditions to check the growth and development of plantlets. Observations on growth and development of somatic embryos were recorded at bimonthly intervals and sub-culturing was carried out into the same media for its growth and development immediately after recording the observations. A photoperiod of 16 h and a temperature of 27±2°C and R.H of 70% were maintained in the culture room.

A LED light fixtures (light strips of 100 cm long 1 cm width consisting of small lamps) were used. for the experiment. The light intensity values (PPFD) were measured with porometer.

The light quality treatments were:

T_1) dark (control-for callus multiplication and somatic embryogenesis)

T_2) W: 100% white LED (400-750) with PPFD of ≅10 μ mol m^{-2} s^{-1}

T_3) B: 100% blue with a wavelength of 450-495 nm and PPFD of ≅ 10 μ mol m^{-2} s^{-1}

T_4) Y: 100% yellow with a wavelength of 570-590 nm and PPFD of ≅ 10 μ mol m^{-2} s^{-1}

T_5) R: 100% red with a wavelength of 610-760 nm and PPFD of ≅ 10 μ mol m^{-2} s^{-1}

T_6) B: R=1:1 light: 50% blue LED light with a wavelength of 450-495 nm and 50% red LED light with a wavelength of 610-760 nm and PPFD of ≅ 20 μ mol m^{-2} s^{-1}

T_7) R: Y=1:1 light: 50% red LED light with a wavelength of 610-760 nm and 50% yellow LED light with a wavelength of 570-590 nm and PPFD of ≅ 20 μ mol m^{-2} s^{-1}

T_8) W: 100% white LED (400-750) with a PPFD of ≅ 100 μ mol m^{-2} s^{-1}

To check the influence of LEDs on callogenesis and somatic embryogenesis of arecanut, observations on increase in callus weight and somatic embryo formation, callus friability, tissue browning, pigment development and vitrification were recorded at monthly intervals continuously for a period of four months. Similarly, to check the growth and development of plantlet, observations on conversion of somatic embryos to plantlets, plantlet growth rate in terms of weight and height, survival, rooting, tendency of multiple shooting, and secondary callogenesis from somatic embryos were recorded at 60 days interval for duration of six months. The recorded values on callogenesis, somatic embryo formation, and plantlet growth and development were subjected to statistical analysis to find out the suitable light source for somatic embryogenesis and plantlet growth of arecanut under *in vitro*.

Completely randomized design (CRD) was used. For testing callus multiplication and somatic embryogenesis four replications were calculated and each Petri plate was considered as one replication. To test the growth and development of plantlets 18 test tubes containing germinated somatic embryos were used for each treatment. The average values of six tubes were considered as one replication. For analysis multiple comparisons of treatments were determined by means of Fisher-least square difference (LSD) test and followed by grouping of treatments using

"agricolae" package in R (Mendiburu, 2020). The level by alpha is 0.05 and p-values were adjusted using bonferroni criteria.

RESULTS AND DISCUSSION

Data on relative growth rate of calli revealed the highest multiplication (0.051 $gg^{-1}d^{-1}$) of embryogenic calli under a combination of red: yellow (1:1) LEDs. This was followed by yellow, white monochromatic LEDs with a callus growth rate of 0.03 $gg^{-1}d^{-1}$ and 0.028 $gg^{-1}d^{-1}$ LEDs subsequently (Table1; Fig.2). Callus multiplication is almost doubled under a combination of red: yellow (1:1) LEDs as compared to the control, i.e., dark incubation. The positive effect of yellow and red LEDs on improving calli weight and somatic embryo formation were observed in *Panax vietnamensis* (Nhut *et al*., 2015) and *Fritillaria cirrhosa* (Chen *et al*., 2020) plants respectively.

Similarly, Soni and Swarnkar (1996) reported callusing and shoot bud formation from leaf cultures of *Vigna aconitifolia* using blue and yellow spectra. In our study, white LEDs with lower light intensity gave better results for multiplication over higher intensity (100 μmol $m^{-2}s^{-1}$). Callus type (friability, compactness, embryonic or organellar calli) decides its multiplication rate. Calli with no apparent organ formation is typically called friable or hard calli (Ikeuchi *et al*., 2013). If calli displays some degrees of organ regeneration it is called rooty, shooty or embryonic callus depending upon the type of organs they develop (Frank *et al*., 2000).

Friable calli of arecanut was found to multiply faster as compared to the compact and organellar calli. The friable and compact organellar callus measured under different LEDs recorded highest friable calli (65%) under a combination of red: yellow (1:1) followed

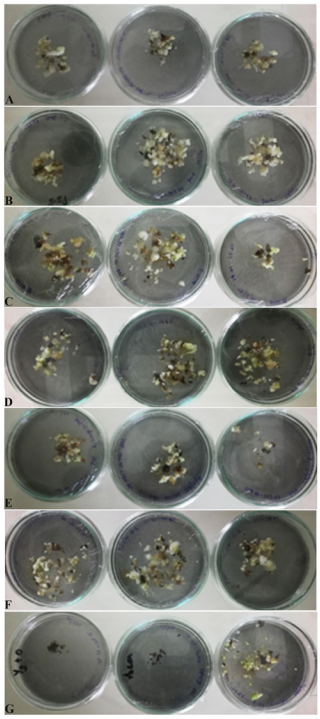

Fig. 1. Embryogenic calli multiplication and somatic embryogenesis in different LED treatments; T_1: dark; T_2: white Lower Intensity; T_3:blue; T_4:yellow; T_5: red; T_6: red: yellow 1:1; T_7: Blue: red 1:1; T_8: White High Intensity

Table 1. Effect of LEDs on callogenesis and somatic embryo formation in Dwarf hybrid line VTLAH-2

Treatment	PPFD (μ mol m^{-2} s^{-1})	Calli wt. (RGR $gg^{-1}d^{-1}$)	Pigmented calli (%)	Somatic embryos / month
T_1-Dark	-	0.026(0.160^b)	0.0 (0.00^c)	30.33(28.33^a)
T_2-White LI	10	0.028(0.168^{ab})	0.0 (0.00^c)	29.00(14.16^a)
T_3- Blue	10	0.025(0.159^b)	25.0(4.98^a)	36.70(29.88^a)
T_4-Yellow	10	0.030(0.169^{ab})	0.00(0.00^c)	38.25(38.25^a)
T_5-Red	10	0.019(0.135^{bc})	8.33(2.85^b)	24.00(16.71^a)
T_6-Red + yellow	20	0.051(0.225^a)	0.00 (0.00^c)	46.1(46.11^a)
T_7-Blue + red	20	0.022(0.148^{bc})	3.33(0.00^c)	18.66 (4.30^a)
T_8-White HI	100	0.008(0.089^c)	0.00 (1.49^b)	6.00 (2.34^a)
Mean		0.026(0.157)	4.58(1.16)	28.63(22.51)
CV (%)		33.40(12.01)	49.79(40.43)	37.03(66.38)
CD (0.05)		0.015(0.03)	3.98(0.83)	18.51(26.17)
S Em		0.005(0.00035)	1.31(0.222)	6.12(223.31)

(The values in parentheses are square root transformed values)

by the control (dark condition) (61%) and yellow LEDs (61%) (Fig.1a), which supports the positive role of a red: yellow LEDs for calli multiplication. Compact organellar calli was found more under red and white (LI) monochromatic LEDs, subsequently resulting in suppression of calli multiplication under these LEDs. Callus browning or necrosis varied from 1.6 to 63% under different LEDs (Fig.1b). Least browning of calli was observed under white coloured LED (10 µmol m^{-2} s^{-1}) with lower intensity i.e.,1.6%, followed by the control (dark) and blue LED with 3% and 5% respectively. Maximum browning (63%) followed by cell death was observed in cultures kept under high light intensity, i.e., white LED with a PPFD of 100 µmol $m^{-2}s^{-1}$. Even though browning of the calli was comparatively high (21%) under yellow LED, regeneration of new calli was found from browned regions. Calli and somatic embryo vitrification was also observed in cultures, and it varied from 1-13%. The vitrified calli and somatic embryos of arecanut were observed to give secondary embryonic calli on same multiplication media.

The data on transformations of calli into somatic embryos was also done. Under certain stress conditions callus cells undergo the process of somatic embryogenesis in which embryos are formed from the adult somatic cells. Number of somatic embryos (SEs) formed from embryogenic calli on callus multiplication media were counted under different treatments showed maximum SE from a combination of red: yellow (46), which was followed by yellow (38) and blue (36) monochromatic LEDs separately, while least embryo formation was seen in white LED with a PPFD of 100 µmol $m^{-2}s^{-1}$ (Table1). Similarly, Chen *et al*. (2020) also reported the highest number of somatic embryos under red LEDs in *Fritillaria cirrhosa*.

Survival percentage of germinated somatic embryos under different LEDs varied from 40 -76%. Significant variability among treatments was not observed for survival of embryos. Relative growth rate of plantlets developed from somatic embryos observed under LEDs ranged from 0.17 - 0.025 $gg^{-1}d^{-1}$. Comparatively higher RGR values were seen in red: yellow (1:1) and white LI (LEDs) as compared to others (Table 2). Arecanut plantlet growth was sluggish in almost all treatments irrespective of LED colour and intensity. A combination of red and blue LEDs at appropriate ratios and optimal intensities enhanced the growth and development of rice (red 50%: blue 50%; 300 µmol $m^{-2}s^{-1}$) *Panax vietnamensis* (red 60%: blue 40%; 25µmol $m^{-2}s^{-1}$), and *Camellia oleifera* (red 80%: blue 20%, 50 ± 5 µmol $m^{-2}s^{-1}$) (Nhut *et al*., 2015; He *et al*., 2020). But in our study, tested LED treatments did not show significant differences (Table 2).

Variation in rooting percentage among different LEDs ranged from 10-46%. Highest rooting percentage (46%) was observed in plantlets maintained under red: yellow (1:1) and white LEDs with high intensity (100 µmol $m^{-2}s^{-1}$), while lowest rooting was (10%) observed under yellow LED. Influences of LEDs on rooting of *in vitro* grown plants were noticed in several species. Blue coloured LED stimulated the rooting in *Vanilla planifolia*

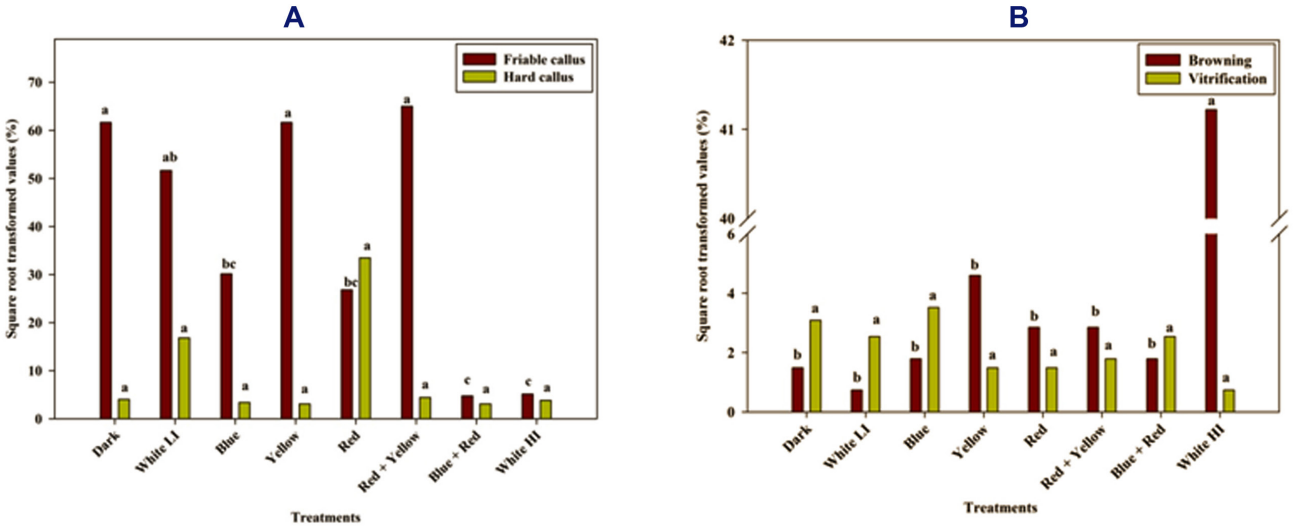

Fig. 2. Influence of different LEDs on (a), arecanut calli type and its multiplication, (b), calli browning and vitrification

Table 2. Effect of LEDs on tissue cultured plantlet growth and development

Treatment	PPFD (μ mol m^{-2} s^{-1})	Survival (%)	RGR-ht. ($cm.cm^{-1}d^{-1}$)	RGR-wt. ($g.g^{-1}d^{-1}$)	Rooting (%)	(%)Calli formation	Somatic embryogenesis (%)	Multiple shooting(%)
T_1-White LI	10	52.59 (27.80^a)	0.001 (0.032^a)	0.024 (0.152^a)	26.98(26.9^{ab})	59.67 (37.56^a)	62.45 (17.48^a)	38.99 (34.70^a)
T_2-Blue	10	66.74 (44.62^a)	0.004 (0.063^a)	0.017 (0.129^a)	15.87(12.36^b)	48.23(27.61^a)	45.45 (45.45^a)	44.44 (40.24^a)
T_3-Yellow	10	63.01 (38.27^a)	0.006 (0.068^a)	0.017 (0.131^a)	10.31 (2.62^b)	63.56 (63.56^a)	52.45 (52.45^a)	38.88 (38.88^a)
T_4-Red	10	40.47 (34.80^a)	0.003 (0.041^a)	0.016 (0.125^a)	15.15 (3.14^b)	59.36 (37.24^a)	56.58 (26.37^a)	22.22 (22.22^a)
T_5-Red + yellow	20	76.66 (27.19^a)	0.010 (0.105^a)	0.025 (0.157^a)	46.94 (46.94^a)	38.88(33.21^a)	36.10 (30.43^a)	31.11 (28.83^a)
T_6-Blue + red	20	52.85 (52.85^a)	0.004 (0.063^a)	0.019 (0.136^a)	18.253 (3.48^b)	47.29(47.29^a)	44.52 (37.85^a)	38.88 (34.69^a)
T_7-White HI	100	55.29 (55.29^a)	0.005 (0.069^a)	0.018 (0.134^a)	46.94 (46.94^a)	74.67(47.31^a)	71.95 (47.22^a)	55.55 (55.55^a)
Mean		58.23 (40.12)	0.0047(0.062)	0.0194 (0.138)	25.78 (20.35)	55.95(55.72)	52.79 (36.75)	13.18 (36.44)
CV (%)		30.81 (41.68)	62.11 (41.26)	28.34 (14.37)	56.33 (51.42)	29.53 (55.73)	33.18 (65.00)	62.00 (69.74)
CD (0.05)		N/A (29.75)	N/A (0.05)	N/A (0.04)	25.68 (18.62)	N/A (41.61)	N/A (42.50)	N/A (45.22)
S.Em		10.36(279.69)	0.002(0.0006)	0.003 (0.0003)	8.386 (109.55)	9.54 (547.13)	10.11(570.77)	13.81(646.08)

The values in parentheses are square root transformed values

(Ramírez-Mosqueda *et al*., 2017). In gerbera, blue and red monochromatic LEDs had positive effect on rooting and plant survival (Pawłowska *et al*., 2018). A composite light of red-blue-purple-green (8:1:1:1) was optimal for getting better rooting rate, root activity and root growth of *Cunninghamia lanceolata* tissue culture seedlings (Xu *et al*., 2020). LEDs were found to have influence on multiple shooting from the developed somatic embryos. Even though 22-55% cultures had exhibited multiple shooting in arecanut, significant differences were not noticed between the LED treatments. This could be due to the addition of cytokinin (6-BAP) to the media to improve the shoot growth. May be the addition of cytokinin along with auxins might have disturbed the cytokinin and auxin balance within the plant system which led to outgrowth of axillary meristems from the plantlet. Similar phenomenon was used in coconut to induce the multiple shoots by suppressing apical meristem using a PGR Tidiazuron (TDZ) (Wilms *et al*., 2021).

Formation of secondary calli was observed from the basal portions of germinated somatic embryos. These secondary calli suppressed the plantlet growth and accelerated the process of secondary somatic embryogenesis. Formation of embryogenic calli was noticed in all the treatments. In this culture 38-74% cultures maintained under different LEDs exhibited secondary calli formation. The calli formed at the distal end of the plantlets subsequently gave rise to the somatic embryos and this process (secondary somatic embryogenesis) continued in all the treatments throughout experimental duration. Significant differences were not noticed among the LED treatments for secondary callogenesis and somatic embryogenesis in arecanut.

CONCLUSION

Thus, there was positive influence of LEDs in arecanut somatic embryogenesis. A combination of red: yellow (1:1) LEDs positively influenced embryogenic calli multiplication and somatic embryogenesis. But the tested monochromatic LEDs and its combinations did not show much influence on subsequent growth and development of somatic embryo originated plantlets. Testing additional combinations along with increased intensity levels may help us to identify the right LEDs suitable for growth of juvenile arecanut plants.

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Effect of pre-harvest application of growth regulators on yield and quality of elephant- foot yam (*Amorphophallus paeoniifolius*) during storage

C Indu Rani[1] and R Neelavathi[2]

Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

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ABSTRACT

The effect of pre-harvest application of growth regulators on yield and quality of elephant-foot yam (*Amorphophallus paeoniifolius* Dennst.) was studied during storage at Horticultural College and Research Institute, TNAU, Coimbatore during 2017-18. Thirteen pre-harvest treatments with cycocel, ethrel and kinetin were used individually and in combination with ridomil at different concentrations 15 and 30 days before harvesting. The combination of cycocel @ 500 ppm + ridomil @ 0.5% sprayed 30 days before harvesting recorded highest mean corm weight (820.60 g) and yield 36.70 tonnes/ha. After harvesting, corms were stored in well-ventilated dry room with relative humidity of 60-75 %. There was a significant loss in corm weight, starch content, dry matter and oxalate content during storage. The corm weight was significantly higher in T_8 (791.60 g), followed by T_{11} (773.30 g) and T_2 (686.10 g) after 6 months of storage. There was no significant loss in starch and dry-matter content in corms in all treatments during storage. The starch content ranged from 8.96 to 10.20% and dry-matter content from 21.50 to 25.25%. The oxalate content was significantly lower in T_8 (115.5 mg/100g), followed by T_2 (120 mg/100g) and T_9 (123 mg/100g).

Key words: Growth regulators, Corm weight, Starch, Dry matter, Oxalate content

Elephant-foot yam *(Amorphophallus paeoniifolius* Dennst.), Araceae, is profitable tuber crops grown in subtropical and tropical region of the world. Growth regulators plays an important role in regulating morphological characters (Shankaraswamy *et al.,* 2015). Chemicals influence the dormancy breaking (Muthuraj *et al.,* 2016), yield and quality in elephant-foot yam (Samatha Punna *et al.,* 2018). Oxalate is considered to be anti-nutritional and toxic (Guil-Guerrero, 2014). On storage of corms, oxalate gets reduced. Corms can also be cured in naturally- ventilated barns or other storage structures. Keeping in view, an experiment was conducted to find out the effect of pre-harvest treatments on tuber weight, yield, starch and calcium oxalate content in elephant-foot yam.

MATERIALS AND METHODS

The elephant-foot yam variety Appakoodal local was used. The experiment was laid out in a randomized block design with 13 treatments replicated thrice each in a plot size of 4.5 m × 4.5 m during 2017-18. The corms were planted at a spacing of 90 cm × 90 cm. Two crops were raised for two consecutive years, post-harvest and storage studies were conducted. The following 13 pre-harvest treatments using cycocel, ethrel and kinetin were used individually and in combination with ridomil at different concentrations 15 days and 30 days before harvesting for improving the quality of storage life.

After 8 months, corms were harvested and stored at room temperature under well-ventilated and dry room with relative humidity of 60-75 %. The data were recorded on mean corm weight (g), corm yield (t/ha), starch content (%), dry-matter content (%) and oxalate content (mg/100 g) at weekly intervals to assess quality of treated yam. The data were subjected to statistical analysis (Panse and Sukhatme, 1985).

RESULTS AND DISCUSSION

There was a significant difference in mean corm weight after pre-harvest application of growth regulators. The treatment T_8 (cycocel @ 500 ppm + ridomil @ 0.5% 30 days before harvesting) recorded highest mean corm weight (820.60 g), followed by treatment T_{11} (cycocel @ 500 ppm + ridomil @ 0.5% 15 days before harvesting) with individual corm weight of 806.30 g as compared to the control (390.00 g). The treatment, T_8 (cycocel @ 500 ppm + ridomil @ 0.5%

Corresponding author : indunathan@gmail.com
[2]ICAR-Krishi Vigyan Kendra, Tindivanam, Villupuram

Table 1. Effect of pre-harvest treatment on yield and quality immediately after harvesting

Treatment	Mean corm weight (g)	Corm yield (tonnes/ha)	Starch content (%)	Dry-matter content (%)	Oxalate content (mg/100 g)
T_1	390.00	16.70	10.15	22.25	693.00
T_2	722.60	31.30	10.84	24.00	151.00
T_3	563.60	28.50	10.42	21.00	595.00
T_4	488.00	22.20	10.28	23.00	181.00
T_5	721.60	30.90	10.70	22.00	184.00
T_6	540.60	29.30	10.41	22.50	183.00
T_7	434.30	19.70	10.24	20.00	393.00
T_8	820.60	36.70	11.03	23.00	151.00
T_9	679.60	30.90	10.55	21.03	204.00
T_{10}	528.60	24.50	10.31	23.25	280.00
T_{11}	806.30	32.40	11.00	20.78	232.00
T_{12}	587.30	28.90	10.51	22.25	356.00
T_{13}	410.60	18.90	10.23	21.50	356.00
Mean	**591.82**	**26.99**	**10.51**	**22.04**	**304.54**
SEd	0.54	0.68	2.08	1.66	1.16
CD (p=0.05)	0.27	0.34	1.54	0.88	0.58

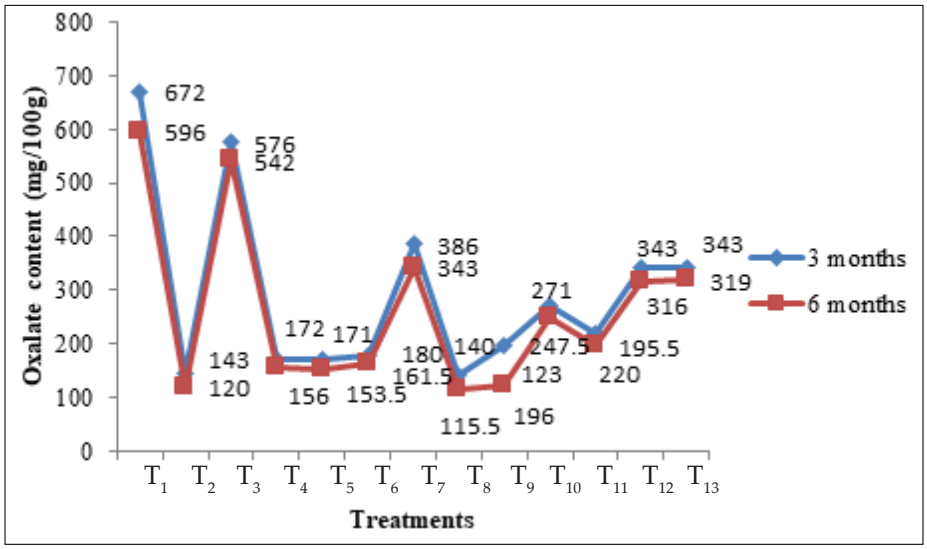

Fig. 1. Effect of pre-harvest growth regulators on oxalate content during storage

30 days before harvesting) showed highest yield of 36.70 tonnes/ha followed by T_{11} (cycocel @ 500 ppm + ridomil @ 0.5% 15 days before harvesting) with yield of 32.40 tonnes/ha.

There was non-significant difference in starch and dry-matter content of corms. There was a significant difference in oxalate content in corms after pre-harvest application of growth regulators. The oxalate content was significantly lower in T_8 (151.00 mg/100g) and T_2 (151.00 mg/100g), followed by T_4 (181.00 mg/100g), T_6 (183.00 mg/100g) and T_5 (184.00 mg/100g) compared to the control T_1 with highest oxalate content (693.00 mg/100 g) (Table 1).

Under well-ventilated and dry room, yams can be stored up 6 months. There was a significant loss in corm weight, starch content and dry-matter content

Table 2. Effect of pre-harvest growth regulators on corm weight, starch and dry-matter content during storage

Treatment	Mean corm weight (g)		Starch content (%)		Dry-matter content (%)	
	3 months	6 months	3 months	6 months	3 months	6 months
T_1	373.30	359.30	9.65	9.41	25.25	23.75
T_2	695.30	686.10	9.83	9.75	27.00	25.00
T_3	541.00	528.00	9.20	9.03	23.50	22.00
T_4	464.60	456.30	9.08	8.96	24.90	24.00
T_5	700.05	683.15	10.00	9.72	24.15	23.00
T_6	518.30	512.60	10.01	9.85	25.00	23.50
T_7	403.30	402.60	9.90	9.65	23.20	21.50
T_8	795.60	791.60	10.25	10.03	26.00	24.50
T_9	649.30	641.00	10.01	9.86	25.75	23.05
T_{10}	512.00	489.60	9.89	9.80	27.20	25.25
T_{11}	806.30	773.30	10.53	10.20	24.00	22.78
T_{12}	572.30	564.30	10.03	9.91	24.30	22.99
T_{13}	398.60	381.60	9.97	9.82	24.00	22.50
Mean	**571.53**	**559.19**	**9.87**	**9.69**	**24.94**	**23.37**
SEd	1.453	0.705	0.534	0.936	1.958	1.423
CD (p=0.05)	0.725	0.352	0.267	0.468	0.979	0.711

T_1, control; T_2, cycocel @ 500 ppm 30 days before harvesting; T_3, ethrel @ 250 ppm at 30 days before harvesting; T_4, kinetin @ 100 ppm 30 days before harvesting; T_5, cycocel @ 500 ppm 15 days before harvesting; T_6, Ethrel @ 250 ppm 15 days before harvesting; T_7, kinetin @ 100 ppm 15 days before harvesting; T_8, cycocel @ 500 ppm + ridomil @ 0.5% 30 days before harvesting; T_9, ethrel @ 250 ppm + ridomil @ 0.5% 30 days before harvesting; T_{10}, kinetin @ 100 ppm + ridomil @ 0.5% 30 days before harvest; T_{11}, cycocel @ 500 ppm + ridomil @ 0.5% 15 days before harvesting; T_{12}, ethrel @ 250 ppm + ridomil @ 0.5% 15 days before harvesting; T_{13}, kinetin @ 100 ppm + ridomil @ 0.5% 15 days before harvesting.

during storage. Reduction in weight may be due to respiration and water loss. Growth regulators have an inhibitory effect on wound healing and periderm formation. The corm weight was significantly higher in T_8 (791.60 g), followed by T_{11} (773.30 g) and T_2 (695.10 g) after 6 months of storage. There was non-significant loss in starch and dry-matter content in all treatments during storage. The starch content ranged from 8.96 to 10.20% and dry-matter content from 21.50 to 25.00%. The oxalate content was significantly lower in T_8 (115.5 mg/100g), followed by T_2 (120 mg/100g) and T_9 (123 mg/100g) (Table 2). Decrease in total oxalate content in corms was found during storage (Singh *et al.,* 2018).

CONCLUSION

The pre-harvest foliar spraying of cycocel @ 500 ppm + ridomil @ 0.5% 30 days before harvesting improved the quality of corms. The oxalate content significantly lower in T_8 (115.5 mg/100g), followed by T_2 (120 mg/100g) and T_9 (123 mg/100g).

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Effect of growing environment on graft compatibility and its success in cucurbits

Deepa Adiveppa Holer[1], N Basavaraja[2], C N Hanchinamani[3], Sandhyarani Nishani[4], Satish D[5] and Ambika D S[6]

Kittur Rani Channamma College of Horticulture, Arabhavi, University of Horticultural Sciences, Bagalkot, 591 218, Karnataka, India

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ABSTRACT

The experiment was conducted to evaluate the effect of growing environment on graft compatibility and its success in cucurbits, at Kittur Rani Channamma College of Horticulture, Arabhavi, Belagavi district, Karnataka, during *kharif* 2018-19 and *rabi* 2019-20 seasons. Among both growing environments (open field and shade net condition), field transplanted grafted plants did not survive 20 days after grafting, hence study was continued to know the performance of grafted plants under shade net condition. Graft compatibility and its success was significantly influenced by different cucurbitaceous rootstocks and scions. Significant and maximum graft success (89.33 and 96.33 %), maximum vine length (227.30 and 269.91cm 40 DAG), minimum number of days to first and 50 % sprouting, final girth of graft union (16.36, 20.04, 13.37, 16.39 at 60 & 90 DAG), node number to first female flower appearance (19.14, 8.28) and days to first female flower appearance (33.15, 45.62) were noticed in *Momordica charantia* L. and *Luffa acutangula* L. scions grafted on *Cucurbita moschata* L. and *Trichosathes cucumerina* L. rootstocks during both seasons and there was non-significant difference between two seasons.

Key words: Cucurbits, Graft compatibility, Graft success, Growing environment, Wedge grafting method,

The family cucurbitaceae includes about 118 genera and 825 species, many of which are economically important crops (Saroj and Choudary, 2020). Continuous cropping can cause abiotic and biotic stresses (incidence of cucurbit pest and soil-borne diseases. Chemical pest control is expensive and is not effective and can harm environment (Davis *et al*., 2008). To overcome many of these problems an alternative technology is grafting. Therefore, an experiment was conducted at Kittur Rani Channamma College of Horticulture, Arabhavi, UHS, Bagalkot, Karnataka, to find out the effect of growing environment on graft compatibility and its success in cucurbits using wedge grafting method.

MATERIALS AND METHODS

The experiment was conducted at Kittur Rani Channamma College of Horticulture (KRCCH), Arabhavi, Belagavi district, Karnataka, during *kharif* 2018-19 and rabi 2019-20 seasons. Two growing environments (open field and shade net condition), five cucurbitaceous species as a rootstocks, *viz.* bottle gourd *(Lagenaria siceraria* L.*)*, pumpkin (*Cucurbita moschata* L.*)*, ivy gourd (*Coccinia indica* L.) sponge gourd *(Luffa cylindrical* L.*)*, snake gourd (*Trichosanthes cucumerina* L.) and five different cucurbitaceous species as scions, *Viz.* watermelon (*Citrullus lanatus L.*), cucumber (*Cucumis sativus* L.), muskmelon *(Cucumis melo* L.), bitter gourd (*Momordica charantia* L.) and ridge gourd *(Luffa acutangula* L.*).* Grafting was performed by using wedge grafting in a factorial randomized block design with three replications.

RESULTS AND DISCUSSION

There was significant difference among rootstocks on number of days taken for first and 50 % sprouting. Significant and minimum number of days to first sprouting were noticed when snake gourd (R_3) (3.17 4.67, 4.17 6.50 days) was used as a rootstock, followed by pumpkin (R_2) (4.33 6.50 8.00 days). The significant and maximum number of days to first sprouting were observed in bottle gourd (R_1) (5.83

Corresponding author: deeparh22@gmail.com
[2,4,5]University of Horticultural Sciences, Bagalkot
[3]Department of Vegetable Science, GKVK, Bengaluru
[6]ICAR –Krishi Vigyan Kendra, Kolar, Karnataka

6.67, 9.50 9.67 days) as a rootstock during both the seasons. The pooled data recorded least number of days to first and 50 % sprouting (3.92, 5.33 days) when snake gourd (R_3) was used as a rootstock. Maximum number of days to first and 50 % sprouting (6.25, 9.58 days) was recorded in bottle gourd (R_1) as a rootstock. These results may be due to early callus formation and wound healing due to faster cell multiplication and cell division at graft portion, resulting in early sprouting and vice-versa for delayed sprouting.

There were significant differences among scions for days taken to first sprouting. Significant and least number of days to first sprouting were observed when ridge gourd (S_2) (4.11 5.33 days) was used as a scion, whereas maximum number of days to first sprouting was noted in bitter gourd (S_1) (4.77 5.89 days) as a scion during both seasons. The pooled data recorded least number of days to first sprouting (4.72 days) in ridge gourd (S_2) and maximum number of days to first sprouting (5.33 days) in bitter gourd (S_1) scion. Similar results were also observed for days to 50 % sprouting. Among different scions, bitter gourd (S_1) took minimum number of days to 50 % sprouting (6.11, 7.67 and 6.89 days) compared to ridge gourd (S_2) during both seasons and mean respectively. This is logically due to physiological conditions of juvenile and younger scions which favored early callus formation due to higher cellular activity.

The interaction effects of different rootstock and scion was also significant during both seasons. Significant and least number of days to first and 50 % sprouting (3.00 4.33, 4.00, 6.33days) was recorded in ridge gourd scions grafted on snake gourd rootstock using wedge grafting method (R_3S_2) and it was at par with bitter gourd scions grafted on snake gourd (R_3S_1) (3.33 5.00, 4.33 4.33 days) rootstock. This may be attributed due to synergistic effects of higher temperature and relative humidity inside healing chamber and also high compatibility of scion and rootstock which ultimately helps in early callus formation due to higher cellular activity and early wound healing.

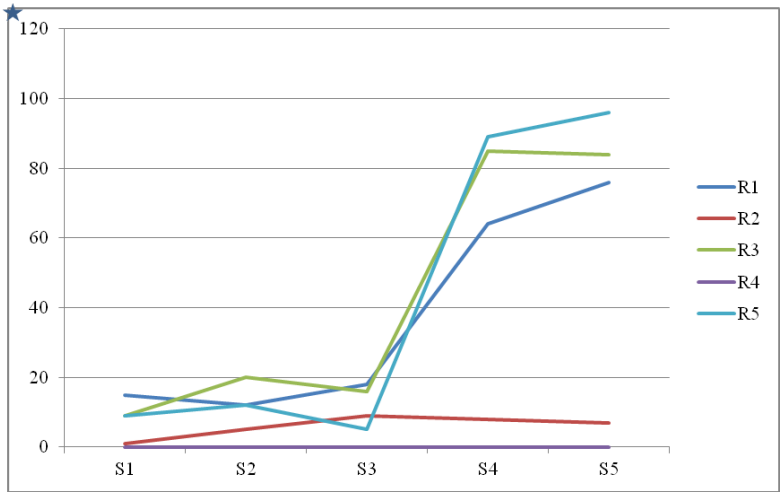
These findings are in line with these of Kavya (2017), and Khandekar *et al.* (2006). Maximum number of days to first sprouting (6.67 7.33, 9.67 9.67 days) was observed in bitter gourd scions grafted on bottle gourd (R_1S_1) as a rootstock. The pooled data recorded minimum number of days to first and 50 % sprouting (3.67 5.17 days) in ridge gourd scions grafted on snake gourd (R_3S_2) and maximum number of days to first sprouting in bitter gourd scions grafted on bottle gourd (R_1S_1) (7.00 9.67 days) rootstock.

The percentage of graft success was assessed in bottle gourd, *Coccinia*, pumpkin, sponge gourd and snake gourd and five different cucurbitaceous scions (watermelon, cucumber, muskmelon, bitter gourd and ridge gourd). Among these combinations, only bitter gourd and ridge gourd scions grafted on bottle gourd, pumpkin and snake gourd rootstocks were found compatible while other all combinations were incompatible. It may be attributed to environmental factors, lack of skill of grafter or premature death of either rootstock or scion due to incompatibility (Fig.1). Further more than 50 % graft success combinations were used for further investigation.

There was highest percentage of graft success (10 DAG) by snake gourd (R_3) (92.50 and 90.50 %), followed by pumpkin (R_2) (87.83 and 85.50 %) and in bottle gourd (R_1) (71.00 and 68.00 %) as a rootstock during both seasons. The pooled mean showed highest percentage of graft success in snake gourd (R_3) (92.25 %), followed by pumpkin (R_2) (87.00 %) and lowest in bottle gourd (R_1) (70.00 %) rootstock. Oda *et al*. (1993) also revealed that maximum percentage of graft success in pumpkin. Similarly, ridge gourd (S_2) recorded maximum percentage of graft success (86.00 and 84.67 %) compared to bitter gourd (S_1) (81.56 and 78.00 %) scion during both seasons. Pooled mean recorded maximum percentage of graft success in ridge gourd (S_2) (85.39%) compared to bitter gourd (S_1) (80.78 %) scion. This may be due to survival rate of grafted plants was inversely correlated with difference in diameters of scion and rootstock and number of vascular bundles (Yetsari and Sari, 2004).

Interaction effects were also found to be significant during both seasons. Ridge gourd scions grafted on snake gourd (R_3S_2) recorded maximum percentage of graft success (97.00, 95.33 %), followed by bitter gourd scion grafted on pumpkin (R_2S_1) (90.67, 86.33 %) and lowest in bitter gourd scions grafted on bottle gourd (R_1S_1) (66.00, 62.00 %) rootstock during both seasons. The pooled data showed maximum percentage of graft success in ridge gourd scions grafted on snake gourd rootstock (R_3S_2) (96.33 %), followed by bitter gourd scions grafted on pumpkin rootstock (R_2S_1) (89.33 %) and lowest in bitter gourd scions grafted on bottle gourd rootstock (R_1S_1) (64.83 %).

Among two seasons the highest percentage of graft success and minimum number of days to 50 % sprouting was noticed during *kharif* (2018-19) than



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Rootstocks: R_1, bottle gourd; R_2, coccinia; R_3, pumpkin; R_4, sponge gourd; R_5, and snake gourd;
Scions: S_1, watermelon; S_2, cucumber; S_3, muskmelon; S_4, bitter gourd; and S_5, ridge gourd;

Fig. 1: Compatibility of cucurbitaceous rootstocks and scions on graft success

Table 1: Effect of cucurbitaceous rootstock and scion on scion length, girth of graft union and number of nodes 20 days after grafting

Treatment	Length (cm)			Initial girth of graft union (mm)		Number of nodes/graft
	10 DAG	15 DAG	20 DAG	10 DAG	20 DAG	15 DAG
R_1	16.22	20.73	15.90	4.83	4.22	1.95
R_2	16.18	20.53	16.52	5.53	5.08	2.28
R_3	20.23	24.21	19.89	5.28	4.62	3.23
SEm±	0.89	1.35	1.15	0.05	0.08	0.34
CD at (5 %)	2.80	NS	NS	0.17	0.25	NS
S_1	18.52	21.60	18.12	5.01	4.33	2.48
S_2	16.56	22.03	16.75	5.42	4.95	2.48
SEm±	0.73	1.10	0.94	0.04	0.06	0.28
CD at (5 %)	NS	NS	NS	0.14	0.20	NS
R_1 S_1	15.49	20.55	16.45	4.62	3.92	1.89
R_1 S_2	16.95	20.90	15.34	5.04	4.52	2.00
R_2 S_1	20.94	20.91	18.45	5.47	5.03	3.22
R_2 S_2	11.41	20.14	14.58	5.58	5.12	1.34
R_3 S_1	19.14	23.35	19.45	4.93	4.03	2.34
R_3 S_2	21.32	25.06	20.34	5.63	5.20	4.11
SEm±	1.26	1.1	1.62	0.07	0.11	0.48
CD at 5 %	3.96	NS	NS	0.24	0.35	1.51
CV (%)	12.41	15.12	16.10	2.49	4.13	33.31

R_1S_1, bitter gourd scions grafted on bottle gourd rootstock; R_1S_2, ridge gourd scions grafted on bottle gourd rootstocks; R_2S_1, bitter gourd scions grafted on pumpkin rootstock; R_2S_2, ridge gourd scions grafted on pumpkin rootstocks; R_3S_1, bitter gourd scions grafted on snake gourd rootstock; and R_3S_2, ridge gourd scions grafted on snake gourd rootstocks
DAG, Days after grafting; NS, Non -significant

rabi (2019-20). Similar findings were also noticed in standardization of grafting in bitter gourd (Akhila and George, 2017). The probable reasons may be the fact that temperature and humidity play important role that influence graft healing by callus formation (Hartmann *et al.*, 2000.

Successful graft combinations were transplanted under open field and shade net condition 8 days after

Table 2: Graft success and vegetative parameters as influenced by cucurbitaceous rootstock and scion under protected environment (shade net)

Treatment 2018-19		Graft success (%) 10 DAG		Vine length (cm) 40 DAG		No. of nodes/graft 60 DAG		Girth of graft union (mm) 60 DAG		Girth of graft union (mm) 90 DAG		Node number to first female flower appearance		Days to first female flower appearance
		2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Rootstock	R_1	71.00 (57.48)	70.00 (56.85)	207.11	198.90	81.84	80.94	10.92	11.55	12.79	13.10	18.60	18.92	45.77
	R_2	87.83 (69.71)	87.00 (68.92)	227.62	224.63	90.90	93.02	12.91	13.11	14.96	15.21	14.70	14.61	41.50
	R_3	92.50 (74.94)	92.25 (74.45)	250.26	248.60	92.73	94.85	14.96	14.87	18.13	18.21	13.68	13.71	39.94
	SEm±	**0.40**	**0.47**	**2.36**	**1.71**	**1.03**	**1.25**	**0.33**	**0.21**	**0.34**	**0.36**	**0.93**	**0.91**	**1.25**
	CD at (5 %)	**1.26**	**1.49**	**7.43**	**5.39**	**3.23**	**2.61**	**1.04**	**0.67**	**1.06**	**1.16**	**2.95**	**2.88**	**3.95**
Scion	S_1	81.56 (65.43)	80.78 (64.80)	221.08	212.53	126.78	126.62	13.60	13.96	16.32	16.45	21.87	22.42	45.36
	S_2	86.00 (69.31)	85.39 (68.68)	235.58	235.56	50.19	52.58	12.26	12.38	14.26	14.56	9.46	9.08	39.44
	SEm±	**0.33**	**0.38**	**1.92**	**1.40**	**0.84**	**1.02**	**0.27**	**0.17**	**0.27**	**0.30**	**0.77**	**0.74**	**1.02**
	CD at (5 %)	**1.03**	**1.22**	**6.06**	**4.04**	**2.64**	**2.13**	**0.85**	**0.54**	**0.86**	**0.95**	**2.41**	**2.36**	**3.23**
Interaction	R_1S_1	66.00 (54.32)	64.83 (53.61)	206.50	197.97	124.45	122.43	11.03	11.83	13.73	13.76	27.00	28.18	45.94
	R_1S_2	76.00 (60.65)	75.17 (60.09)	207.73	199.83	39.23	39.45	10.81	11.26	11.85	12.45	10.20	9.65	45.60
	R_2S_1	90.67 (72.22)	89.33 (70.92)	229.87	212.32	130.45	130.29	13.40	13.72	15.36	15.55	19.64	19.93	45.00
	R_2S_2	85.00 (67.19)	84.66 (66.93)	225.37	236.94	51.34	55.75	12.43	12.51	14.55	14.87	9.77	9.30	38.00
	R_3S_1	88.00 (69.75)	88.17 (69.86)	226.87	227.30	125.45	127.15	16.39	16.36	19.88	20.04	18.97	19.14	45.13
	R_3S_2	97.00 (80.09)	96.33 (79.04)	273.65	269.91	60.00	62.56	13.53	13.37	16.37	16.39	8.40	8.28	34.74
	SEm±	**0.56**	**0.66**	**6.39**	**2.42**	**1.45**	**1.77**	**0.46**	**0.30**	**0.47**	**0.52**	**1.33**	**1.29**	**1.77**
	CD at 5 %	**1.78**	**2.11**	**10.50**	**7.63**	**4.57**	**3.69**	**1.48**	**0.94**	**1.50**	**1.65**	**4.18**	**4.08**	**5.59**
	CV (%)	**1.16**	**1.39**	**2.53**	**1.87**	**2.81**	**2.26**	**6.28**	**3.92**	**5.38**	**5.83**	**14.66**	**14.24**	**7.25**

* Rootstocks : R_1, Bottle gourd; R_2, Pumpkin; R_3, Snake gourd

Scion(S) : S_1,Bitter gourd; S_2,Ridge gourd

DAG, Days after grafting NS, Non-significant

* Figures in parentheses are arcsine transformation

grafting (after healing). Sudden wilting of grafted plants under open field condition was observed 20 days after grafting (DAG). This may be due to transplant shock or disease attack or climatic condition of the place which may not be suitable for cultivation of grafted plant under open field condition (Table 1).

Sprout length of scion under shade net condition recorded at 10 days after grafting was found to be non-significant, whereas at 15, 20, 25, 30 and 40 days after grafting it was significantly affected by different treatment combinations. Number of node/ graft/vine at 15 DAG was also found to be non significant and at 30, 45 and 60 days after grafting found to significant. The initial girth of graft union recorded at 10, 20 and 30 DAG was also found to be non- significant.

Pooled data showed maximum vine length (248.60 cm), maximum number of nodes/graft (94.85) (93.02), final girth of graft union (14.87, 18.21 mm at 60 and 90 DAG) (13.11 15.21 mm at 60 and 90 DAG), least number of days to first sprouting (39.94) (41.50), appearance of first female flower at early node (13.68) (14.70) in snake gourd (R_3), followed by pumpkin (R_2) rootstock respectively compared to bottle gourd (R_1) as a rootstock (Table 2). This might be attributed to strong and vigorous root system of both pumpkin and snake gourd rootstocks which promoted growth and also wider diameter and strong stem of snake gourd and pumpkin compared to bottle gourd with more number of vascular bundles for strong stem girth.

Interaction effects were also found to be significant. Maximum vine length (269.91 cm) (227.30 cm), maximum number of nodes/graft (130.29) (62.56) in ridge gourd and bitter gourd scions grafted on snake gourd and pumpkin rootstock respectively, final girth of graft union (16.36, 20.04) (13.37, 16.39 mm at 60 and 90 DAG) in bitter gourd and ridge gourd scions grafted on snake gourd rootstock. Minimum number of days to first female flower appearance (33.15) (45.62) and appearance of first female flower at earliest node (19.14) (8.28) in both ridge gourd and bitter gourd scions grafted on snake gourd rootstock respectively. This may be due to strong and extended roots of both pumpkin and snake gourd which helps to absorb more water and nutrient elements leading to vigorous plant growth and flowering parameters. There was no difference between two seasons. This clearly indicates that the rootstocks were more stable under different environmental conditions, giving nearly the same vegetative and flowering parameters. A similar finding was also observed by Mohamed *et al*. (2012) in watermelon.

CONCLUSION

Thus the best rootstocks for both bitter gourd and ridge gourd are pumpkin and snake gourd with respect to graft compatibility and graft success and vegetative and flowering parameters. Open field cultivation grafted plants can be tried using mulching and drip irrigation systems for more yield.

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Effect of frontline demonstration on yield and economics of okra (*Abelmoschus esculentus*) in Dungarpur district of Rajasthan

Madan Lal Choudhary*, R.A. Kaushik** and M. C. Bhateshwar*

**SKN College of Agriculture, SKNAU, Jobner-Jaipur*
***Directorate of Extension Education, MPUAT, Udaipur*

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ABSTRACT

The frontline demonstration on okra [*Abelmoschus esculentus* (L.) Moench.] was conducted on 70 ha during 2016, 2017, 2018 and 2019 at farmers' fields in tribal area of Dungarpur district of Rajasthan. A total of 350 demonstrations were conducted on 350 farmers fields' with package of practices. The average yield was obtained 145.9, 147.5, 148.6 and 150.2 q/ha under demonstrated practice, whereas in farmers practice it was 102.2, 103.1, 102.6 and 103.4q/ha yield during summer season of 2016, 2017, 2018 and 2019, respectively. An average on technology gap of four years frontline demonstration programme was 3.95qha. The per cent increase in yield with high-yielding over local variety was 42.76 to 45.26 per cent. The extension gap recorded was 43.7, 44.4, 46.0 and 46.8 q/ha during all years. An average technology index was 2.60 per cent during all the four years, showing the efficacy of technical interventions. The demonstrated practice also gave higher gross return, net return with higher benefit: cost ratio compared to farmers practice.

Key words: B:C ratio, Extension gap, FLD, Technology gap, Technology index, Yield.

Okra [*Abelmoschus esculentus* (L.) Moench] thrives in all kinds of soils, but it grows best in a friable well manured soil (Yawalkar, and Ram, 2004). Farmers in India are still producing crops based on knowledge transmitted to them by their forefathers leading to a grossly unscientific agronomic, nutrient management and pest management practices (Papnai, *et al*. 2017). As a result, they often fail to achieve the desired potential yield. To improve yield levels and make awareness to okra growers, frontline demonstrations were conducted. The performance of okra Jamuna against local check was evaluated at farmers' fields during summer seasons 2016 to 2019.

MATERIALS AND METHODS

The frontline demonstrations were conducted in Dungarpur district during summer season 2016, 2017, 2018 and 2019. A total 350 frontline demonstration on okra Jamuna was conducted at farmers' fields. The data were collected on pod yield, cost of cultivation, net returns with benefit: cost ratio. The data were collected through personal contacts with the help of well-structured interview schedule. The data were processed, tabulated, classified and analyzed in terms of mean per cent score. More than 10 per cent difference between beneficiary and non-beneficiary farmers was considered as significant difference. The extension gap, technology gap and technology index, marginal benefit: cost ratio and relative economic efficiency were calculated using the formula as suggested by Papnai *et al*. (2017).

Extension gap = demonstrated practice yield- farmers practice yield

Technology gap = potential yield- demonstration yield

$$\text{Technology index} = \frac{\text{Potential yield - demonstration yield}}{\text{Potential yield}} \times 100$$

RESULTS AND DISCUSSION

On an average pod yield was recorded 148.05q/ha under demonstrated practices as compared to farmers' practice (102.18q/ha). The highest pod yield of demonstrated practices was 150.20q/ha during summer season 2019 and in farmers' practice (103.10q/ha). The lowest yield was during summer season 2016. Average pod yield increased 44.92%/ha. The higher average pod yield was due to technical knowledge and adoption of improved package of practices. The findings support to those of Singh *et al*. (2008), Dhemre and Desale (2010), Singh *et al*. (2011), Nanda and Saha (2014), Khaiwal (2014), Yadav and Verma (2015),

Corresponding author: mlchoudhary75@gmail.com

Kacha and Patel (2015), Rajput *et al*. (2016), Papnai *et al*. (2017), Choudhary *et al*. (2017), Aklade *et al*. (2018), Shelke *et al*. (2019), Adhikari and Piya (2020), Kachari and Barooah (2020), Ray *et al*. (2020), Sivakumar *et al*. (2020), Irulandi, *et al*. (2020), Bhati *et al*. (2021) and Choudhary *et al*. (2022). However, variations in yield might be due to variations in soil fertility, moisture availability, rainfall and change in location.

The yield of demonstration practices was 6.1q/ha, 4.5q/ha, 3.5g/ha and 1.8q/ha during summer season 2016, 2017, 2018 and 2019, respectively. An average on technology gap of four years frontline demonstration programme was 3.95qha. The technology gap might be attributing to dissimilarity in soil fertility status and weather conditions. Hence, location-specific recommendations depend on identification and use of farming situation, specific interventions and greater implications in enhancing system productivity. These findings are similar to those of Singh *et al*. (2008), Singh *et al*. (2011), Balai *et al*. (2013), Kacha and Patel (2015), Rajput *et al*. (2016), Choudhary *et al*. (2017), Aklade *et al*. (2018), Sivakumar *et al*. (2020), Kachari and Barooah (2020), Ray *et al*. (2020), Bhati *et al*. (2021) and Choudhary *et al*. (2022). Extension gap of 43.7q/ha, 44.4q/ha, 46.0q/ha and 46.8q/ha was observed during all seasons.

An average of extension gap under frontline demonstration programme was 45.23q/ha, which emphasized the need to educate the farmers for adoption of improved production technology. These findings are similar to those of Singh *et al*. (2008), Balai *et al*. (2013), Singh *et al*. (2011), Kacha and Patel (2015), Rajput *et al*. (2016), Choudhary *et al*. (2017), Aklade *et al*. (2018), Sivakumar *et al*. (2020), Kachari and Barooah (2020), Ray *et al*. (2020), Bhati *et al*. (2021) and Choudhary *et al*. (2022). The technology index varied from 1.18 to 4.01 per cent. An average technology index was 2.60% during all years, which showed the efficacy of technical interventions.

The technology index showed economic feasibility of the demonstrated technology at farmers' fields. Therefore, it is concluded that understanding and using improved varieties/ hybrids with recommended scientific package of practices enhanced yield. These are in agreement with those of Singh *et al*. (2008), Singh *et al*. (2011), Balai *et al*. (2013), Kacha and Patel (2015), Rajput *et al*. (2016), Choudhary *et al*. (2017), Aklade *et al*. (2018), Kachari and Barooah (2020), Sivakumar *et al*. (2020), Ray *et al*. (2020), Ray *et al*. (2020), Bhati *et al*. (2021) and Choudhary *et al*. (2022).

The net return of ₹110400/ha, ₹139450/ha, ₹169250/ha and ₹185250/ha, respectively, were obtained as

Table 1. Economics and yield difference of okra Jamuna under frontline demonstrations

Year	No. of Demo.	Area (ha)	Yield (q/ha)		increase yield over FP%	Extension Gap (q/ha)	Technology gap (q/ha)	Technology Index (%)	Cost of cultivation (₹/ha)		Gross return (Rs/ha)		Net return (₹/ha)		B:C ratio	
			DP	FP					DP	FP	DP	FP	DP	FP	DP	FP
2016	50	10	145.9	102.2	42.76%	43.7	6.1	4.01	35500	34950	145900	102200	110400	67250	4.11	2.92
2017	100	20	147.5	103.1	43.06%	44.4	4.5	2.96	37550	37050	177000	123720	139450	86670	4.71	3.34
2018	100	20	148.6	102.6	44.83%	46.0	3.4	2.24	38790	38250	208040	143640	169250	105390	5.36	3.76
2019	100	20	150.2	103.4	45.26%	46.8	1.8	1.18	40050	39020	225300	155100	185250	116080	5.63	3.97
Mean	**350**	**70**	**148.05**	**102.83**	**43.98%**	**45.23**	**3.95**	**2.60**	**37973**	**37318**	**189060**	**131165**	**151088**	**93848**	**4.95**	**3.50**

DP = Demonstrated practice, FP = Farmers practice and Potential Yield (q/ha) = 152

compared to farmer practices ₹67250/ha, ₹.86670 /ha, ₹105390/ha and ₹116080/ha during summer seasons of 2016, 2017, 2018 and 2019, respectively (Table 1). The average net return of ₹1,51,088/ha was higher as compared to farmers practices (₹93,848/ha). An average cost of cultivation, gross return, additional net return and B: C ratio of demonstration practice was ₹37973/ha, ₹189060/ha, ₹57240/ha and 4.95, respectively as compared to farmers practice (₹37318/ha), gross return (₹131165/ha) and B : C ratio (3.50). The benefit: cost ratio was higher than farmers' practices in during all the years. This may be due to higher yield under improved technologies compared to farmers' practice. This finding is similar to those of Singh *et al*. (2008), Singh *et al*. (2011), Balai *et al*. (2013), Khaiwal (2014), Nanda and Saha (2014), Yadav and Verma (2015), Kacha and Patel (2015), Rajput *et al*. (2016), Choudhary *et al*. (2017), Papnai *et al*. (2017), Aklade *et al*. (2018), Sivakumar *et al*. (2020), Ray *et al*. (2020), Bhati *et al*. (2021) and Choudhary *et al*. (2022).

CONCLUSION

These yield potential of okra can be increased to a great extent. This will substantially increase the income as well as livelihood of farming community. There is a need to adopt multi-pronged strategy that involves enhancing okra production through improved technologies in tribal area of Dungarpur district of Rajasthan.

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Variability assessment in fruits of seedling origin guava (*Psidium guajava*)

Murari Lal Chopra*, Krishan Kumar, Vikas, Megha Ahir, Priynka Kumari Jat and Heerendra Prasad

Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan 173 230

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ABSTRACT

The experiment was conducted to assess variation among existing guava (*Psidium guajava* L.) trees of seedling origin. A total of 60 healthy and bearing trees were marked for studies during 2017-18 at RHR&TS, Dhaulakuan, Himachal Pradesh. There was variation in fruit shape (round to pyriform), colour of fruit skin (yellow, yellow white and yellow green) and fruit shape at stalk end (rounded to broadly rounded). The variation in fruit weight, fruit length, fruit width, length/width ratio, number of seeds/fruit, fruit yield, yield efficiency, TSS, acidity, ascorbic acid, total sugars, reducing sugars, non-reducing sugars were 65.22-128.57g, 4.40-6.18, 4.90-6.51, 0.87-1.31cm, 12-411, 16.0-34.8kg/tree, 2.27-24.6g/cm^2, 7.35-11.83^{o}Brix, 0.270-0.627%, 138.19-249.43mg/100g, 5.13-8.38%, 3.22-5.44% and 1.81-2.83%, respectively. Out of 60 trees, four were designated as "elite" based on overall distinct attributes. The identification of one seedless (tree No. 22), one approximate seedless (tree No. 21), two red fleshed genotypes (tree No. 57 and tree No. 58) having desirable traits was a significant finding.

Key words: Fruit, Genotype, Seedling origins, TSS, Variability

Guava (*Psidium guajava* L.) is a tropical fruit crop. This resulted in the accumulation of variability followed by its exploitation to select better genotypes, a large number of varieties with different taste, flavour, sweetness and other qualities were developed through selection (Khalil *et al*., 2015). Most of the existing semi-wild plantation comprises old seed-raised trees. Out of these a number of seedling trees in bearing may be potentially suitable for table purpose. But there has not been a concerted effort to document and exploit this variable gene pool. Thus, there is an absolute need to determine and exploit existing genetic variability in guava (Patel *et al*., 2011).

MATERIALS AND METHODS

The experiment was conducted at Regional Horticultural Research and Training Station, Dhaulakuan, Himachal Pradesh, during 2017-18. A total of 60 healthy and bearing trees of seedling origin were marked. The 20-year-old bearing seedling tree planted 7m × 7m apart, were marked. The total annual rainfall of about 80% was recorded during July and September.

A total of 20 fruits were selected randomly from all directions from each individual tree for evaluation as per standard descriptor for guava prescribed by UPOV (UPOV, 1987). The fruit maturity, fruit weight, fruit length, fruit width, length/width ratio, fruit shape, fruit shape at stalk end, number of seeds/fruit and seed hardness were evaluated. Colour of fruit skin and flesh was assigned as per colour chart of Royal Horticultural Society (Wilson, 1941). Yield of each plant was recorded on weight balance from first harvesting to last harvesting. The yield efficiency of each selected tree was calculated as per Westwood (1993) and expressed in g/cm^2 TCSA using the formula:

$$\text{Yield efficiency (g/cm}^2\text{)} = \frac{\text{Yield (g/plant)}}{\text{TCSA (cm}^2\text{)}}$$

Total soluble solid (TSS) was determined with the help of digital refractometer. Biochemical analysis of fruit quality was done as per standard procedure described of AOAC (1980). The mean values of data were subjected to analysis of variance as per the procedure of by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The variation was observed in days from full bloom to maturity from 78 to 91 days during 2017 and 76 to 108 days during 2018. The maximum (91 days) fruit maturity was recorded in tree No. 16 and minimum (78 days) in tree No. (24 and 25) during 2017. In 2018, maximum (108 days) fruit maturity was observed in tree No. 4 and minimum (76 days) in tree No. 49. Mostly seedling guava trees produced green to yellowish type of fruits. There was significant variation in fruit skin colour. The fruits belonged to following classes: yellow green 151C (9), yellow green 151 A (3),

***Corresponding author :** m.l.chopra2@gmail.com

yellow green 153 C (10), yellow green 153A (5), yellow green 145A (5), yellow white 148C (5), yellow 143 C (2), yellow 143A (4), yellow 142 C (11) and yellow 144 C (6).

Significant variation in flesh colour was also observed with red fleshed in 2 trees and white pulp in rest of the trees. Fruit shape round in all seedling trees except pyriform in tree No. 25. Fruit shape at stalk end was rounded in 41 trees and broadly rounded in 19 guava seedling trees. The variation in morphological characters of fruits is largely in accordance with those of Dubey *et al*., 2016; Nasution and Hadiati, 2014; and Ulemale and Tambe, 2015.

A significant variation in fruit weight was recorded. Mean fruit weight among 60 guava trees was 94.06g. The maximum fruit weight was observed in tree No. 47 (128.57g) and minimum fruit weight (65.22g) in tree No. 8. Coefficient of variation was recorded as 13.65 % in pooled analysis. Fruit length depicts fruit shape as fruits with higher values possess pyriform shape, while lower values indicate round fruit shape. The maximum fruit length was found in tree No. 25 (6.18cm) and minimum in tree No. 24 (4.40cm) with an average length of (5.25cm).

Coefficient of variation was recorded as 7.04 % in pooled analysis. A significant variation was observed in fruit width ranging from (4.90cm) in tree No. 56 to (6.47cm) in tree No. 47 with a mean value of 5.47cm. Coefficient of variation was recorded as 6.55 % in pooled data. The variation in length/width ratio was maximum (1.31) in tree No. 25 and minimum (0.87) in tree No. 18 with mean length/width ratio of 0.94. Coefficient of variation was recorded as 3.96 % in pooled data. Considerable variation in physical attributes of guava has been reported (Khalil *et al*., 2015; Singh *et* al., 2015; Patil *et al*., 2015; Dubey *et al*., 2016 and Abo-El-Ez *et al*., 2017. Variation in physical dimensions is, by and large, the outcome of both genetic constitution and crop regulation practices.

The mean number of seeds/fruit was of 270.18. The minimum number of seeds/fruit was recorded 12 seeds in tree No. 21 and maximum seeds (411) in tree No. 18. Coefficient of variation was recorded as 27.16 %. Interestingly, tree No. 22 produced seedless fruits, indicating its significant. The variation in seed hardness/ softness ranged from hard in 38 trees, semi-hard in 19 trees and soft in only 2 trees, tree No. 9 and tree No. 30. The latter two selections offer scope for bringing about genetic improvement. These results are in agreement with those of Khalil *et al*., 2015; Dubey *et al*., 2016; Anupa *et al*., 2017 and Abo-El-Ez *et al*., 2017. The number of seeds/fruit could be a potential selection index given its additive gene nature (Rajan *et al.,* 2005), as it also recorded considerably high coefficient of variation.

The variation in fruit yield ranged from (16.00 kg/ tree) in tree No. 22 to (34.28 kg/tree) in tree No. 9 with a mean value of 24.64 kg/tree. Coefficient of variation was 17.35 %. The significant variation was observed in yield efficiency, maximum (24.67 g/cm^2) in tree No. 55 and minimum (2.27 g/cm^2) in tree No. 37. The mean value was recorded as 7.81 g/cm^2 and coefficient of variation was 56.52 % in pooled data for yield efficiency. The overall variation in yield per tree was recorded low as compared to yield efficiency. Similar variation in fruit yield has been reported Marak and Mukunda (2007), Ulemale and Tambe (2015) and Anupa *et al*., (2017). However, low levels in fruit yield may be due to inherent seedling nature compared to grafted trees.

Total soluble solids varied between 7.35^o Brix in tree No. 26 and 11.83^o Brix in tree No. 7 with mean value of 10.17^o Brix. Coefficient of variation was recorded as 10.80 %. A significant variation was also observed in acidity with maximum (0.627%) in tree No. 56 and minimum (0.270%) in tree No. 15 with overall mean of 0.412%. Coefficient of variation was recorded as 22.92 % in pooled analysis. The ascorbic acid content in pooled values was maximum (249.43mg/100g) in tree No. 57 and minimum (138.19 mg/100g) was recorded in tree No. 28 with an overall mean of 181.45 mg/100g.

Coefficient of variation was found 14.95 % in pooled data. The minimum and maximum total sugar content were recorded in tree No. 26 (5.13%) and in tree No. 39 (8.38%), respectively. Mean total sugar content among 60 guava trees was 6.96 %. Coefficient of variation was recorded as 10.12 %. The maximum reducing sugar was observed in tree No. 39 (5.44%) and minimum (3.22%) in tree No. 26 and mean reducing sugars among 60 guava trees was 4.49 %. Coefficient of variation was recorded as 10.23 % in pooled data. A review of pooled data indicate that maximum non-reducing sugars were recorded in tree No. 25 (2.88 %) and minimum in tree No. 26 (1.81 %) with an overall mean of 2.35 %. Coefficient of variation was recorded as 10.55 % in pooled analysis. Similar results were obtained by Khalil *et al*., 2015; Dubey *et al*., 2016; and Abo-El-Ez *et al.,* 2017; Srivastava *et al*., 20022. The low levels of variation in major biochemical constituents of the fruits indicates lesser possibilities of exploitation of this gene pool for chemical fruit quality.

Table 1. Variation in fruit (biochemical) characters of guava seedling trees (two-year pooled data)

Tree No	TSS (°Brix)	Acidity (%)	Ascorbic Acid (mg/100g)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)
1	9.07	0.374	151.57	6.48	4.19	2.18
2	10.78	0.457	140.04	7.32	4.73	2.46
3	10.74	0.307	159.49	7.15	4.60	2.42
4	9.50	0.357	144.61	6.76	4.36	2.28
5	11.76	0.337	157.23	8.10	5.24	2.71
6	10.08	0.508	208.05	6.77	4.36	2.28
7	11.83	0.355	188.17	8.30	5.36	2.78
8	7.94	0.484	190.39	5.73	3.70	1.92
9	7.75	0.309	174.27	5.82	3.76	1.95
10	9.31	0.458	203.60	6.38	4.13	2.14
11	8.94	0.454	147.19	6.39	4.11	2.16
12	11.30	0.296	178.79	7.84	5.09	2.60
13	9.50	0.347	199.11	7.08	4.61	2.34
14	8.84	0.562	178.89	6.12	3.96	2.04
15	10.79	0.270	152.79	7.31	4.60	2.57
16	9.85	0.324	185.87	6.92	4.36	2.43
17	10.56	0.430	167.41	7.12	4.48	2.51
18	8.80	0.385	188.76	6.44	4.05	2.26
19	9.45	0.478	151.30	6.61	4.16	2.32
20	10.26	0.289	156.40	7.05	4.42	2.50
21	10.88	0.323	217.66	7.31	4.60	2.57
22	10.75	0.316	203.07	6.95	4.38	2.44
23	11.60	0.548	186.28	7.84	4.92	2.76
24	9.90	0.312	169.67	6.61	4.16	2.33
25	11.35	0.472	179.23	8.01	5.03	2.83
26	7.35	0.604	196.25	5.13	3.22	1.81
27	10.63	0.301	185.39	7.12	4.48	2.51
28	10.75	0.378	138.19	7.15	4.50	2.51
29	11.55	0.471	180.29	7.89	5.03	2.72
30	9.75	0.483	168.43	6.53	4.17	2.23
31	10.56	0.519	193.11	7.51	4.76	2.61
32	8.74	0.321	181.25	6.18	3.94	2.12
33	10.34	0.371	206.67	7.39	4.78	2.47
34	10.60	0.376	216.03	7.21	4.68	2.40
35	9.70	0.434	188.66	6.48	4.20	2.17
36	11.51	0.541	199.00	7.94	5.17	2.63
37	9.80	0.300	215.19	6.57	4.27	2.19
38	9.80	0.428	147.66	6.49	4.22	2.16
39	11.80	0.508	178.74	8.38	5.44	2.79
40	11.50	0.313	147.64	7.98	5.18	2.66
41	9.55	0.301	232.80	6.79	4.41	2.26
42	11.25	0.340	172.38	7.99	5.18	2.66
43	11.35	0.572	231.79	7.44	4.84	2.47
44	11.10	0.502	167.05	7.32	4.76	2.44
45	9.66	0.378	161.77	6.69	4.35	2.22
46	8.00	0.319	146.79	5.72	3.71	1.91
47	11.00	0.493	246.81	7.63	5.04	2.46
48	9.90	0.286	183.39	6.66	4.40	2.15
49	10.90	0.331	151.42	7.40	4.88	2.39

50	9.55	0.561	180.26	6.76	4.46	2.18
51	11.80	0.410	219.51	7.95	5.25	2.57
52	9.80	0.371	191.06	6.59	4.31	2.16
53	11.10	0.352	186.90	7.17	4.69	2.35
54	8.45	0.454	201.80	5.74	3.76	1.88
55	10.55	0.609	147.44	6.24	4.09	2.04
56	10.15	0.627	168.26	6.68	4.37	2.19
57	8.70	0.510	249.43	5.97	3.91	1.96
58	9.73	0.431	205.08	6.65	4.35	2.18
59	11.35	0.380	146.73	7.30	4.78	2.39
60	10.20	0.435	164.24	6.73	4.41	2.21
Mean±SE	10.17±0.14	0.41±0.011	181.45±3.50	6.96±0.09	4.49±0.06	2.35±0.03
SD	1.10	0.09	27.13	0.70	0.46	0.25
CV (%)	10.80	22.98	14.95	10.12	10.23	10.55

CONCLUSION

Thus, there was high degree of morphological variation in guava seedling trees. High to moderate levels of coefficient of variation was recorded for yield efficiency and number of seeds/fruit suggesting their suitability as a selection criteria for crop improvement.

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GA_3 priming, biopriming and hydropriming effect on quality nursery production of China aster (*Callistephus chinensis*)

Shabnam Pangtu, Puja Sharma, SR Dhiman, Prashant Sharma, Divesh Thakur

Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan 173230 Himachal Pradesh, India

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ABSTRACT

The study was carried out at Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, on China aster [*Callistephus chinensis* (L.) Nees] cv 'Poornima' and 'Kamini' in nursery under open field conditions in randomized block design (factorial) comprising eight seed priming treatments, viz. control, hydropriming with water, priming with GA_3 (50, 100 and 150 ppm) and biopriming with *Trichoderma viride* @ 1×10^4 cfu/ml, 1×10^5 cfu/ml and 1×10^6 cfu/ml for 24 hr. There was maximum speed of germination (18.97, 21.58), germination percentage (83.17, 86.33 %), root length (2.87, 2.93 cm), shoot length (6.39, 6.59 cm), seedling length (9.26, 9.52 cm), seedling dry weight (227.67, 248.30 mg), seed vigour index-I (769.89, 822.19), seed vigour index-II (18,934.33, 21,436.62); minimum time taken to seed germination (12.72, 11.33 days) and days required to reach 4-6 leaf stage (23.70, 22.33 days) with priming treatment GA_3 (100 ppm) in Poornima and Kamini, respectively. Hence, it is concluded that seeds of Kamini treated with GA_3 (100 ppm) for 24 hr obtained best results for most of the desirable character for quality nursery production of China aster.

Key words: Germination, Nursery, Priming, Quality, Bioprianing, Hydropriming

China aster [*Callistephus chinensis* (L.) Nees] is an important commercial flower belonging to family Asteraceae. Flower production of China aster is often hampered by the availability of poor quality of seeds, which is mostly connected with unfavourable weather conditions during seed development and maturation (Yu-jie *et al*., 2009). One such method of improvising the seed quality is seed priming, i.e. controlled hydration followed by redrying that helps to reduce germination time, harmonize germination, improves seed germination rate and quality of seedlings for the better crop establishment in many crops (Varier *et al*., 2010). The plant growth regulators like GA_3 has improved the growth and yield parameters in many fruit crops (Patil *et al*., 2017; Priyadarshi and Hota, 2021). Seed priming has presented surprise results for flower crops like pansy, marigold, gladiolus and China aster. Primed seed has effective results on growth, flowering (Pangtu *et al*., 2018) and seed yield (Pangtu *et al*., 2018). Therefore, effect of seed priming on quality nursery production of China aster.

***Corresponding author :** shabnam.pangtu34@gmail.com

MATERIALS AND METHODS

The study was carried out at Dr YS Parmar, University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The primed seeds along with non-primed seeds were sown in raised beds in July under open field conditions. For nursery bed preparation, soil was dug up to a depth of 30 cm and well-rotten farmyard manure at the rate of 5 kg/m^2 was added and mixed well. Raised nursery beds about 6 inch from ground and 2 m × 3 m (length × breadth) were prepared. In nursery beds, treatments were arranged in a randomized blocked design (factorial) having eight treatments with three replications each containing 200 seeds. Seeds were sown in rows 5 cm apart. After placing seeds in rows, these were covered with a fine layer of sieved farmyard manure. Irrigation of nursery bed was done with the help of watering can having fine rose. Nursery bed was then covered with polyethylene sheet. This polyethylene sheet was removed as soon as seeds start germinating. Seedlings of about four to six leaf stage were used for transplanting.

The priming agents required for various seed priming treatments were obtained from the Departmental laboratory and accordingly the desired concentrations were prepared using distilled water as per the details given below:

For hydro-priming 200 seeds were kept in 9 cm Petri-dish on filter paper and moistened with 5ml distilled water. All the petri dishes were kept at 23°C in incubator for 24 hr. Then, seeds were taken out and spread in a thin layer on blotting paper for drying under room conditions.

In order to prepare 50 ppm GA_3 solution, 50 mg of GA_3 powder was weighed with the help of digital electronic balance and dissolved in small amount of distilled water and final volume was made one litre by adding distilled water. Seeds (200 seeds) were kept in 9 cm Petri dish on filter paper and moistened with 5ml of GA_3 (50 ppm) solution. All the Petri dishes were kept at 23°C in incubator for 24 hr. Then, the seeds were taken out and spread in a thin layer on blotting paper for drying under room conditions. Similarly, GA_3 (100 ppm) and GA_3 (150 ppm) solutions were prepared using 100 mg and 150 mg GA_3 powder in one litre of distilled water, respectively. Then the seeds were also treated in the same way as that of priming with GA_3 50 ppm.

The *Trichoderma viride* culture was procured from Department of Mycology and Plant Pathology, Nauni, Solan. The population density that resulted in formation of 10^4 cfu/ml of fungal isolates were used for preparation of liquid formulation. The 200 seeds were soaked in liquid culture of *Trichoderma* formulation in sterilized petri dishes. All the petri dishes were kept at 23°C in incubator for 24 hr. Then, the seeds were taken out and spread in a thin layer on blotting paper for drying under room conditions. The formulation of *Trichoderma viride* @ 1×10^5 and cfu/ ml (P_7) and *Trichoderma viride* @ 1×10^6 cfu/ ml (P_8) were also prepared in a similar manner and seeds were treated in the same manner as that of biopriming with *Trichoderma viride* @ 1×10^4 cfu/ ml. The effect of seed priming treatments on germination and seedling vigour of China aster under nursery conditions was observed.

RESULTS AND DISCUSSION

The higher speed of germination was noticed in Kamini as compared to Poornima. It may vary from cultivar to cultivar and such differences exist and may be attributed to their genetic make up and environmental conditions. Different seed priming treatments exhibited varied responses to speed of germination. Priming of seeds with P_4 (GA_3 @ 100 ppm) resulted in highest speed of germination. The possible reason for getting enhanced speed of germination with GA_3 (100 ppm) might be ascribed to the fact that GA_3 accelerated various metabolic reactions before germination.

These findings are in conformity with those work of Kumar and Singh (2013). However, minimum speed of germination recorded in non-primed seeds might be ascribed to slow metabolic reactions in non-primed seeds and consequently they took more time to enhance the process of germination. The less time to seed germination was observed in Kamini over Poornima. It is obvious that variation might be attributed to the genetic makeup of these cultivars. Among seed priming treatments, less time taken to seed germination was observed with GA_3 (100 ppm).

The GA_3 might have increased the á- amylase activity for breaking starch stored in seeds to alter the physiology of embryo and activated enzymes which accelerate various developmental processes (Basra *et al.,* 2005). These results are in close proximity with those of Montero *et al.* (1990), Sharma (2012) and Kaya *et al.* (2010) were of the same opinion that GA_3 (100 ppm) primed seeds took lesser time for germination in pea and chickpea, respectively.

Maximum germination percentage was noticed in Kamini over Poornima. As, it may vary from cultivar to cultivar and such differences exist and being attributed due to their genetic makeup and environment conditions. Among different seed priming, treatments maximum germination was noticed in the seeds primed with GA_3 @ 100 ppm. The possible reason for getting maximum germination with GA_3 treatment might be due to the fact that during germination, GA_3 activated the enzymes that digested the endosperm carbohydrates rapidly and efficiently and reduced the mechanical restraints of endosperm thus, providing energy to start and sustain embryo growth. Similar findings were reported by Montero *et al.* (1990). Kumar and Singh (2013) and Sharma (2012) were of same opinion while working on bitter gourd and pea, respectively.

The effect of seed priming on days required to reach 4- 6 leaf stage in both the cultivars. Required less time to reach 4-6 leaf stage as compared to cv. 'Poornima'. The variation might be due to their genetic make up and environmental conditions.

Table 1. Effect of priming treatment on quality nursery production

Priming treatment	Seedling length (cm)			Seedling dry weight (mg)			Seedling vigour index-I			Seedling vigour index-II		
	Poornima	Kamini	Mean	Poornima	Kamini	Mean	Poornima	Kamini	Mean	Poornima	Kamini	Mean
P_1	7.89	8.13	8.01	148.33	160.76	154.55	485.13	571.81	528.47	9,122.33	11,306.79	10,214.56
P_2	8.72	8.97	8.85	210.50	224.63	217.56	649.89	705.64	677.76	15,682.40	17,670.52	16,676.46
P_3	8.96	9.19	9.07	226.47	247.73	237.10	744.62	792.81	768.72	18,827.24	21,378.87	20,103.05
P_4	9.26	9.52	9.39	227.67	248.30	237.98	769.89	822.19	796.04	18,934.33	21,436.62	20,185.47
P_5	8.85	9.06	8.96	200.74	213.62	207.18	685.34	706.93	696.13	15,550.94	16,662.38	16,106.66
P_6	8.89	9.05	8.97	187.45	232.49	209.97	666.95	694.10	680.52	14,058.83	17,823.79	15,941.31
P_7	9.08	9.29	9.19	227.60	247.67	237.63	753.09	801.42	777.25	18,890.80	21,365.47	20,128.13
P_8	8.85	9.07	8.96	198.25	238.57	218.41	622.49	668.16	645.32	13,943.37	17,573.30	15,758.33
Mean	8.81	9.04		203.38	226.72		672.17	720.38		15,626.28	18,152.22	
$CD_{0.05}$												
Cultivars		0.10			0.29			9.45			127.09	
Treatments		0.20			0.59			18.94			254.19	
Cultivars x Treatments		NS			0.83			NS			359.47	

P_1 = Control, P_2 =Hydropriming, P_3 = GA_3 (50ppm), P_4 = GA_3 (100ppm), P_5 = GA_3 (150ppm), P_6 = *Trichoderma viride* (1 x 10^4 cfu/ml), P_7= *Trichoderma viride* (1 x 10^5 cfu/ml) and P_8 = *Trichoderma viride* (1 x 10^6 cfu/ml).

Among different seed priming treatments, less time to reach 4-6 leaf stage was recorded in seeds primed with GA_3 (100 ppm). This might be ascribed to the fact that GA_3 primed seeds exhibited an early and uniform emergence. Pre-sowing hydration might have softened the seed coat that allowed the leakage of germination inhibitors in the seed and this might have contributed to the enhancement of seed germination and early transplanting of the seedlings (Harris, 1996). Similar findings were reported by Montero *et al.* (1990) in Antirrhinum, Kaya *et al*. (2010) in Chickpea also reported that GA_3 (100 ppm) significantly increase the early seed germination and following transplanting.

Seedlings of Kamini produced maximum root length (cm) as compared to Poornima. The variation might be attributed to genetic makeup of these cultivars. Among seed priming treatments, maximum root length was recorded in the seeds primed with GA_3 (100 ppm). The increased root length following priming with GA_3 might be due to higher rate of cell division in root and shoot tips incited by the application and these studies are in confirmation with work of Montero *et al.* (1990), Kaya *et al*. (2010), Sharma (2012) and Kumar and Singh (2013).

Seedlings of Kamini resulted maximum shoot length (cm) as compared to Poornima. The variation might be attributed to genetic make up of these cultivars. Among priming treatments, maximum shoot length was recorded in the seeds primed with GA_3 (100 ppm). The increasing shoot length following priming with GA_3 might be due to the higher rate of cell division in the root and shoot tips incited by the application of GA_3 and these studies are in conformity with those of Montero *et al.* (1990), Kaya *et al*. (2010), Siadat *et al.* (2012), Sharma (2012) and Kumar and Singh (2013).

Seedling length was noticed to be more in Kamini over Poornima. It is quite obvious that such differences between the two cultivars may exist and can be attributed to their genetic makeup and environment conditions as well. Maximum seedling length observed when seeds were treated with GA_3 (100 ppm). This might be ascribed to the fact that this increase in root and shoot length of the seedlings could be positively be correlated with respect to an increase in seedling length. Similar findings were reported by Montero *et al.* (1990), Kaya *et al.* (2010), Sharma (2012) and Kumar and Singh (2013).

Seedling dry weight was more in Kamini over Poornima. Such differences between two cultivars may be attributed to their genetic make up and environmental conditions. Maximum seedling dry weight was observed in GA_3 (100 ppm) primed seeds. This might be ascribed to the fact that GA_3 is known to enhance the water uptake of the seedlings which might have activated the enzymes with an accompanying mobilization of reserve materials in embryo and thus strongest seedlings were obtained as a result of better embryo growth. This increases the fresh weight of the seedlings which is positively correlated further with the increase in the dry weight of the seedlings. These studies got support from the earlier findings of Muhammad and Rha (2007) who observed the maximum dry weight in Sugar beet seeds on priming with GA_3 (100 ppm).

Seed vigour index- I was more in Kamini over Poornima. Such differences between the two cultivars may be attributed to their genetic make up and environment conditions. Among priming treatments, highest vigour index-I was observed with GA_3 (100 ppm). It might be due to production of longer seedlings. Similar findings were reported by Kumar and Singh (2013).

Seed vigour index- II was noticed to be more in Kamini as compared to Poornima. Such differences may exist between the two cultivars being attributed to their genetic makeup and environment conditions. The treatment with GA_3 @ 100 ppm exhibited highest seed vigour index-II. It might be due to increased á-amylase activity for breaking the starch stored in seeds by growth regulators or salt solutions (Basra *et al.,* 2005). Priming caused *de novo* synthesis of á-amylase (Lee and Kim, 2000) increasing metabolic activities in seeds, which resulted in higher seed vigour. Similar findings were in close proximity to those of studies of Muhammad and Rha (2007).

CONCLUSION

The response of different priming treatments on quality nursery production revealed that GA3 @ 100 ppm improved various nursery quality parameters of China aster Poornima and Kamini.

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Effect of PGRs on growth, reproductive efficiency, and quality of tomato (*Solanum lycopersicum*) in arid regions

Suman Poonia[1], Santosh Choudhary[2]*, S. K. Moond[3], Moola Ram[4] and Ronak Kuri[5]

College of Agriculture, Jodhpur, Agriculture University, Jodhpur-342304 (Rajasthan)

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ABSTRACT

An experiment was conducted during *rabi*, 2021-22 at College of Agriculture, Jodhpur to assess the effect of plant growth regulators (PGRs) on the growth, flowering, and fruiting characteristics; and quality of tomato (*Solanum lycopersicum* L.) in a randomized block design with three replications comprising 10 treatments. Three levels each of GA_3, 4-CPA, and NAA along with control were used. There was maximum plant height (47.2 cm, 61.3 cm, and 80.9 cm at 45 DAT, 60 DAT, and final harvesting, respectively), number of branches (19.4/plant), leaf area (30.6 cm^2), TSS (5.41°Brix) and ascorbic acid (22.8 mg/100g) over the control with GA_3@75 ppm, whereas minimum acidity (0.46 %) was recorded with NAA@75 ppm. The significantly higher fruit length (6.7 cm), fruit diameter (7.2cm), and fruit firmness (2.6 kg/cm^2) were recorded with 4-CPA@75 ppm. The maximum number of fruit clusters (12.0/plant), number of flowers (5.4/cluster), number of fruits (3.2/cluster), number of fruits (38.1/plant), fruit setting (59.7%), fruit weight (84.3 g) and lycopene content (6.5 mg/100g) were observed with NAA@75 ppm.

Key Words: 4-Chlorophenoxy acetic acid, flowering, fruiting, gibberellic acid, naphthalene acetic acid

Tomato (Solanum lycopersicum L.), as India's second most crucial solanaceous vegetable crop, faces challenges due to the sub-optimal growth conditions associated with global warming and climate change in arid regions. These environmental stresses negatively impact plant growth, survival, and crop yield (Choudhary et al., 2023). Besides the importance of growing adapted hybrids to both biotic and abiotic stresses (Singh et al., 2021) the productivity enhancement necessitates application of plant growth regulators (PGRs) for controlling pre-harvest fruit drops and enhancing flowerbud formation and fruit ripening. Among the PGRs, gibberellic acid (GA_3) plays a vital role in controlling various critical processes including stem elongation, enhancing flower maturation, and promoting overall plant growth. The use of GA3 in tomatoes has been shown to increase fruit setting and the number of fruits per plant (Chaudhury et al., 2013), leaf area, lycopene content, the number of fruit clusters, internode elongation, and the number of branches (Masroor et al., 2006). Additionally, 4-chlorophenoxy acetic acid (4-CPA), an auxin, positively affects the quality of tomatoes by influencing sucrose metabolism and altering acid invertase activity during ripening. The application of 4-CPA a week after anthesis has been observed to increase fruit set percentage, number of fruits per plant, fruit weight, diameter, fruits per cluster, and yield per cluster, particularly under low temperatures. Furthermore, naphthalene acetic acid (NAA) also contributes to reducing pre-harvest fruit drops and enhancing fruit setting, size, and yield. Given these challenges and the potential of PGRs, an investigation was conducted to assess the effects of GA3, 4-CPA, and NAA on the growth and quality of tomatoes in the arid regions of western Rajasthan.

MATERIALS AND METHODS

The experiment was conducted during *rabi* 2021-22 at College of Agriculture, Jodhpur, situated at an altitude of 231m amsl between $26^0$15″ to $26^0$45″ North latitude and $73^0$00 to $73^0$29″ East longitude. The location falls in agroclimatic zone of the 'Arid Western Plains Zone' of Rajasthan. The climate of Jodhpur is usually arid, with dry, warm, and sunny winters and

***Corresponding author :** s.choudhary83@yahoo.co.in

[1,2,3,5]College of Agriculture, Jodhpur

[4]AICRP on Pearl Millet, Jodhpur

average annual precipitation is about 367 mm. The average daily maximum and minimum temperature fluctuated between 16.1^{0}C-40.3^{0}C and 10.9^{0}C-36.6^{0}C, respectively, with mean daily relative humidity varying from 88.1-27.1%. The soil of experimental field was sandy-loam in texture, slightly alkaline in reaction (pH 8.2), low in organic carbon (0.13%) and available N (174 kg/ha), and medium in available phosphorus (20.2 kg/ha) and high in available potassium (325 kg/ha).

The experiment comprised 10 treatments including three levels each of GA_3 (25, 50, and 75 ppm), 4-CPA (25, 50, and 75 ppm), and NAA (25, 50, and 75 ppm) along with the control (water spray). The experiment was laid out in a randomized block design with three replications. The experimental field was prepared by two cross-harrowing followed by planking. The FYM @ 25 t/ha was thoroughly incorporated into soil at the time of harrowing. A uniform dose of 120 kg P_2O_5/ha through DAP, 80kg K_2O/ha through MoP, and 60 kg N/ha through urea was applied about 3-4 cm deep at the time of transplanting. The remaining dose of N (60 kg/ha) was applied through urea in two equal splits 35 and 60 days after transplanting (DAT) through spot application.

The 30-day old seedlings of tomato (*cv. Ansal*) were transplanted on 1 December 2021 at 60 cm x 45 cm row-to-plant spacing, respectively on flat beds in plots of 3.15m × 4.20m. The field was irrigated by maintaining uniform soil moisture. Manual weeding was performed twice, and plant-protection measures were adopted as per needs.

A stock solution of 1000 ppm of GA3, 4-CPA, and NAA was prepared in distilled water. Then, working solutions of 25, 50, and 75 ppm each of GA3, 4-CPA, and NAA were prepared by diluting the sock solutions with distilled water. Three foliar sprays of PGRs were applied 30, 45, and 60 days after transplanting (DAT) thoroughly with 500 litre water/ha. Spraying was performed early in morning to avoid rapid drying of the spray solution due to transpiration.

Observations on plant height (45 DAT, 60 DAT, and at final harvesting), number of branches at final harvesting, fruit clusters/plant at final harvesting, flowers/cluster at 75 DAT, fruits/ cluster, and fruits/plant at final harvest were recorded on five randomly selected plants in each treatment. The leaf area/plant was taken after 90 DAT from five mature and active leaves by multiplying leaf length and leaf width. The per cent fruit setting was obtained by dividing total number of fruits/cluster by the number of flowers/cluster and multiplied by 100. The fruit length, fruit diameter, and fruit weight were recorded from five randomly selected fruits from each treatment. The total soluble solids were recorded using a digital refractometer, acidity was measured from pulp of tomato fruit, ascorbic acid was estimated following AOAC (2000), lycopene content through spectrophotometer and fruit firmness was determined by a digital fruit hardness tester.

The means for all data collected from the treatments were calculated and the analyses of variance for all the characters were performed by the 'F' test. The significance of difference between pairs of means was separated by critical difference (CD) at 5% levels of probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

The plant height 45 DAT, 60 DAT, and at final harvesting was influenced significantly under different levels of GA_3 and NAA. Further, under different levels of 4-CPA, plant height was recorded at par of the control. There was maximum plant height of 47.2 cm, 61.3 cm, and 80.9 cm at 45 DAT, 60 DAT, and at final harvesting, respectively over the control with GA_3@75 ppm, which was found at par with GA_3@50 ppm. This may be due to the effect of GA_3 on stem elongation by rapid cell multiplication in sub-apical meristem. The NAA@75 ppm being at par with NAA@50 ppm, recorded significantly maximum plant height of 40.6 cm, 53.0 cm, and 71.3 cm at 45 DAT, 60 DAT and final harvest, respectively over control. Similar results were reported by Ujjwal *et al.* (2018). This might be due to increased photosynthetic activities, better translocation, and utilization of photosynthates due to rapid cell division in apical regions and growth stimulation. However, due to the plant deformity effect, the higher levels of 4-CPA beyond 25 ppm caused a decrease in plant height. It clarifies that higher concentrations of PGRs can impair primary plant metabolisms.

The number of branches/plant at the final harvesting and leaf area/plant at 90 DAT was influenced significantly in GA_3 and NAA over the control. However, due to the plant deformity effect of

4-CPA, number of branches and leaf area/plant could not be influenced significantly over the control. The maximum number of branches (19.4) and leaf area at 90 DAT (30.6 cm^2) were observed with GA_3@75 ppm, which was at par with GA_3@50 ppm (18.9 and 29.7 cm^2, respectively). Similar results were observed by Naz *et al*. (2020). This might be due to antimitotic action, which inhibits the suppression of apical growth of central axis, finally increasing number of branches/plant. On the other hand, GA_3 might have caused an increase in protein and enzyme synthesis, which caused shoot elongation, leading to higher leaf area. Similarly, maximum number of branches (18.2) and leaf area at 90 DAT (27.2 cm^2) were observed with NAA@75 ppm, which was at par with NAA@50 ppm. It may be due to more photosynthetic activities in plants leading to increased leaf area. Similar results were observed by Naz *et al*. (2020).

The number of flowers/cluster at 75 DAT, number of fruit clusters/plant at final harvesting, number of fruits/cluster, number of fruits/plant at final harvesting, fruit setting per cent, length of fruit, diameter of fruit, and fruit weight were observed to be significant, with all levels of GA_3, over the control. The application of GA_3@75 ppm being at par with GA_3@50 ppm recorded maximum flowering and fruiting. Similar results were reported by Singh *et al*. (2019). The more number of flowers/cluster might have been due to more production of flower primordia by GA_3 (Ujjawal *et al*., 2018). The GA_3 might have become more active with extra food reserve, and hence the number of fruits seems to have increased. Besides, the rapid and better nutrient translocation from roots to apical parts of plants makes treated plants physiologically more active, resulting in more flowers and fruit setting. The increased fruit length and diameter might have been due to cell division and multiplication in reproductive organs. The increase in fruit weight might be due to deviation of a major portion of photosynthates from vegetative parts to reproductive ones by GA_3.

The number of flowers/cluster at 75 DAT, number of fruit clusters/plant at final harvesting, number of fruits/cluster, fruit setting, length of fruit, and diameter of fruit were significant over control. The significantly maximum number of flowers/cluster at 75 DAT, length of fruit, and diameter of fruit were recorded with 4-CPA@75 ppm which was found at par to 4-CPA@50 ppm. Similar results were observed by Naz *et al*. (2020). The increased fruit length under the influence of PGRs was due to better vegetative growth and physiological activity, resulting in assimilation built-up in plants, ultimately increasing fruit length. Whereas, number of fruit clusters/plant at final harvesting, number of fruits/cluster, and fruit setting were highest with 4-CPA@25 ppm and it was at par with 4-CPA@50 ppm. Similar results were observed by Akhter *et al*. (2018). This could be attributed to potential of 4-CPA to check flowers and fruit drops. When general effects are examined, it will be seen that 4-CPA encouraged fruit formation even at high concentrations, with related side effects of deformation and parthenocarpy. The lower fruit weight under 4-CPA was attributed to fruit puffiness effect caused by to deforming effects of 4-CPA at higher levels.

Similarly, flowering and fruiting characteristics were significant with all levels of NAA over the control. The maximum number of flowers/cluster at 75 DAT, number of fruit clusters/plant at final harvesting, number of fruits/cluster, number of fruits/plant at final harvesting, fruit setting, length of fruit, diameter of fruit, and fruit weight was observed with NAA@75 ppm, and it was at par with NAA@50 ppm. Similar results were observed by Naz *et al*. (2020). Higher dry matter accumulation due to better photosynthetic and metabolic activities; and efficient nutrient uptake due to hormonal activity of PGR are directly reflected in more fruit clusters (Mahindre, 2017). The higher number of fruits/plant and cluster with NAA applications may be attributed to increased fruit setting and fruit retention. The increase in fruit weight with the application of NAA might be due to the accumulation of adequate photosynthates for developing bigger-sized fruits (Kiranmayi, 2014).

The quality parameters like TSS, acidity, ascorbic acid content, lycopene content, and firmness were influenced significantly by different levels of GA_3 (Table 1). The application of GA3@75 ppm recorded the significantly highest TSS content (5.41°Brix), ascorbic acid (22.8 mg/100g), lycopene content (6.0 mg/100g), and fruit firmness (2.4 kg/cm^2) over the control. Similar results were reported by Naz *et al*. (2020) and Ranjeet *et al*. (2014). The increased TSS content could be due to enhanced leaf area and more carbohydrate production through photosynthesis process (Bhat *et al*., 2021) and increase in fruit firmness may be due to higher juice content, increased amount of cellulose in cell wall of fruit. The application of GA_3 might have converted the fruit acids into sugar and its derivatives by reversal of glycolytic pathways which might have caused a significant decrease in acidity of

Table 1. Effect of different levels of GA_3, 4-CPA and NAA on quality parameters in tomato.

Treatment	TSS (°Brix)	Acidity (%)	Ascorbic acid (mg/100g)	Lycopene content (mg/100g)	Firmness (kg/cm^2)
GA_3@25 ppm	3.83	0.54	18.7	5.5	1.8
GA_3@50 ppm	5.03	0.53	20.5	5.9	2.2
GA_3@75 ppm	5.41	0.52	22.8	6.0	2.4
4-CPA@25 ppm	3.78	0.51	17.1	4.9	1.7
4-CPA@50 ppm	4.77	0.49	16.7	4.6	2.3
4-CPA@75 ppm	5.22	0.47	16.1	4.4	2.6
NAA@25 ppm	3.96	0.51	18.6	5.4	1.5
NAA@50 ppm	4.62	0.48	19.4	6.0	1.7
NAA@75 ppm	4.75	0.46	19.7	6.5	1.8
Control (water spray)	3.45	0.48	16.7	5.0	1.4
SEm±	0.09	0.01	0.52	0.13	0.07
CD (*p*=0.05)	0.27	0.04	1.5	0.4	0.2

GA_3, Gibberellic Acid; 4-CPA, 4-Chlorophenoxy Acetic Acid; NAA, Naphthalene Acetic Acid

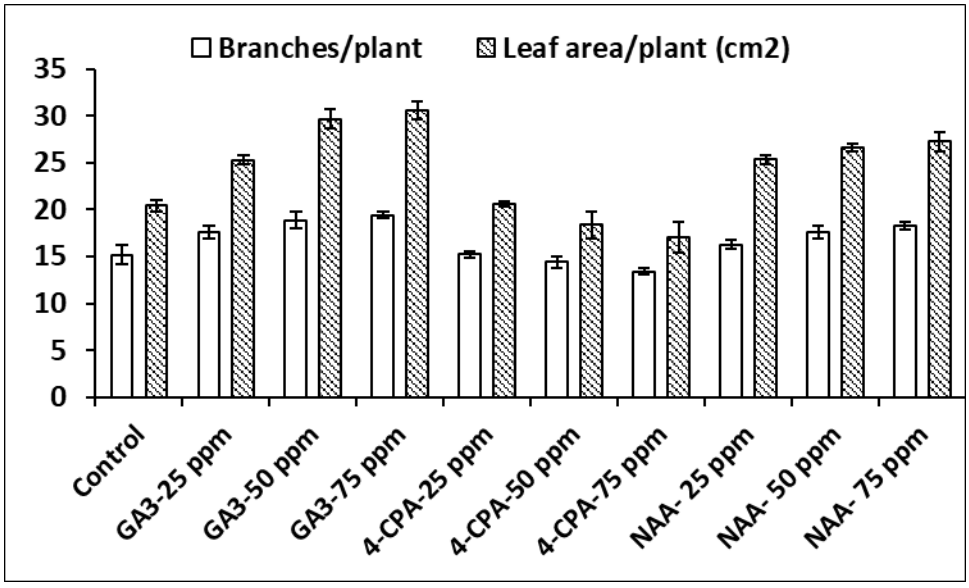

Fig. 1. Number of branches and leaf area/plant as influenced by different levels of gibbrellic acid, 4-CPA and NAA. The error bars represent the standard error.

tomato fruits and minimum acidity was recorded with GA3@75 ppm (0.47%). These results are in agreement with Ranjeet *et al*. (2014) and Naz *et al*. (2020).

Again, different levels of 4-CPA influenced significantly the TSS content and fruit firmness over control. The significantly maximum TSS content (5.22°Brix) and highest firmness (2.6 kg/cm^2) over control was recorded in 4-CPA@75 ppm. This increase in fruit firmness may be due to higher juice content, increased amount of cellulose in the cell wall of the fruit, and therefore increased texture firmness (Weksler *et al*., 2009).

The maximum TSS content (4.75 °Brix), ascorbic acid content (19.7 mg/100g), lycopene content (6.5 mg/100g), and fruit firmness (1.8 kg/cm^2) were recorded over the control with NAA@75 ppm. This may be due to better root development, enhanced nutrient uptake, and better accumulation and translocation of photosynthates into fruits. Similar results were reported by Ahmed *et al.* (2019) in pepper.

CONCLUSION

The application of GA_3 at 75 ppm significantly increased plant height, branches, leaf area, and improving flowering and fruiting, enhancing fruit production and quality parameters. Application of NAA at 75 ppm showed comparable positive effects by increasing branches, leaf area, and fruit setting, leading to higher fruit yield with improved quality. Application of 4-CPA, though causing deformities at higher doses, had positive effects at lower concentrations on flowering and fruiting.

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Short Communication

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Weather-based yield prediction in banana (*Musa* spp.) by using principal component analysis

B. Ajith Kumar and Haritha Lekshmi V.

Department of Agricultural Meteorology, College of Horticulture, KAU, Thrissur

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Banana (*Musa* spp.) production is greatly influenced by weather parameters. Accurate weather-based yield forecast helps planners and policy-makers. Weather-based yield prediction models provide a trustworthy yield forecast, and also helps in forewarning of pest and diseases (Agrawal and Mehta, 2007). According to Salau *et al*., 2016 excessive rainfall and extremely high temperature can reduce banana productivity, while production is also small when both rainfall and temperature are very low with poor humidity. Information on yield climate relationship helps in forecasting yield and formulating suitable policies. Yield prediction or forecasting is an important aspect of developing economy so that proper planning can be undertaken for the sustainable growth.

The field experiments were conducted on banana (cv. Nendran) at College of Agriculture, Kerala Agricultural University, Thrissur, during 2012-2017. Planting was done at 15 days interval in two seasons, *viz.* first season (15th April, 1st May, 15th May, 1st June and 15th June) and second season (15th August, 1st September, 15th September, 1st October and 15th October), with a spacing 2 m × 2m, in three replications in randomized block design. Yield data were collected from each plant for analysis.

Principal component analysis (PCA) was carried out for different weather elements experienced during the crop period using R statistical software. The PCA helps in minimizing the complexity of a data set to a lower appropriate dimension, the contributions of which will be more towards the system that we analysing. It also helps to deal with the multi colinearity of observed weather data. Scree plot and biplot were drawn with the help of R statistical software. By this method, principle components were obtained and were used for fitting regression models

Principle component analysis was carried out with required weather variables and ten principle components were identified with variable proportions. It was observed that a cumulative proportion of 98.9 was obtained for first three components (component 1, component 2 and component 3) (Table 1). Component 1 showed a proportion of variance of 83.23%, component 2 with 9.99% and that for component 3 was 5.73%. Proportion was very less for other seven components. So for yield prediction only first three components were used for fitting regression equation. The variation showed by each component was also depicted using a scree plot (Fig. 1).

The variable factor map was drawn which explains the importance of different weather parameters in forming first two components. The parameters that are closer to yield in variables factor map showed more contribution in forming the components and those

Table 1. Proportion of variance of various component

Principal componenet	Variance percent	Cumulative variance percent
Component 1	83.23	83.23
Component 2	9.99	93.2
Component 3	5.73	98.9
Component 4	0.56	99.52
Component 5	0.34	99.87
Component 6	0.06	99.93
Component 7	0.04	99.97
Component 8	0.01	99.992
Component 9	0.006	99.998
Component 10	0.001	100.00

***Corresponding author :** harithalekshmi8@gmail.com

which had a loading value greater than 0.5 were more influential in formation of corresponding components (Haritharaj, 2019). It is clear that weather parameters like forenoon and afternoon relative humidity are closely related to banana yield (Table 2, Fig. 2). Similar findings were proposed by Rao *et al*. (2002), Regression equations were fitted using three components and are described here,

$$Yield = 5.60+0.331X_1+0.561X_2+0.283X_3$$

Where,

X_1, core of principal component 1; X_2, core of principal component 2; X_3, core of principal component 3

Using this equation the yield (bunch weight per plant) was predicted. A comparison between actual and predicted yield is given in Fig.3. The model overestimated the yield, even though it predicted values close to that of actual yield. Principal component analysis can be used as an effective tool in forecasting yield of banana and it solves the problem with the multi-colinearity of weather variables and large numbers of weather variables are reduced to three principle components by constructing the regression equation.

Table 2. Different weather parameters in forming principal components

Variable	Component 1	Component 2	Component 3
Maximum temperature	-0.340	0.119	-0.071
Minimum temperature	-0.074	0.971	0.145
Forenoon relative humidity	0.345	0.058	0.056
Afternoon vapour pressure deficit	0.345	0.047	0.072
Wind speed	-0.341	-0.022	-0.004
Bright sunshine hours	-0.342	-0.104	-0.082
Rainfall	0.342	-0.021	0.068
Rainy days	0.341	-0.013	0.151
Evaporation	-0.341	-0.023	-0.174

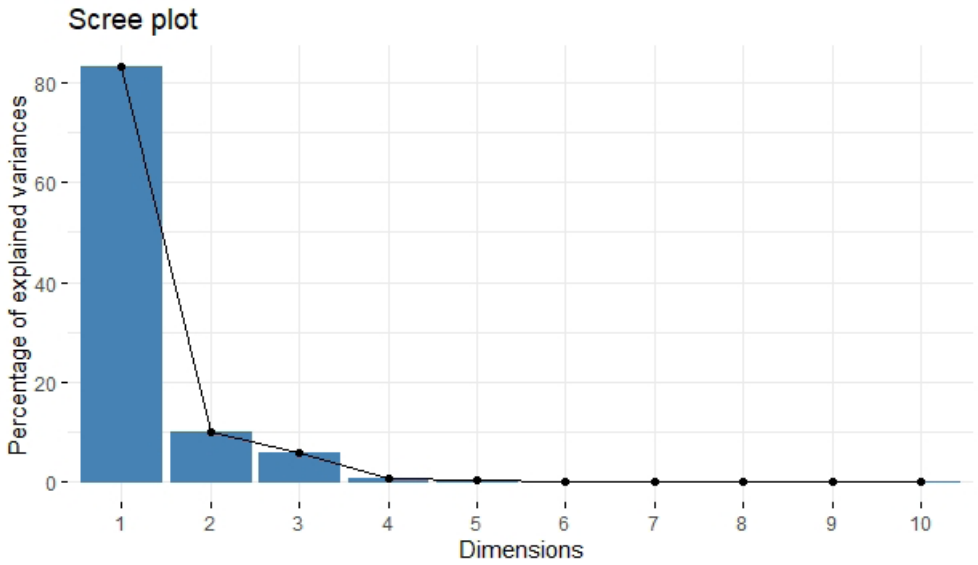

Fig. 1: Variation exhibited by each dimension (component)

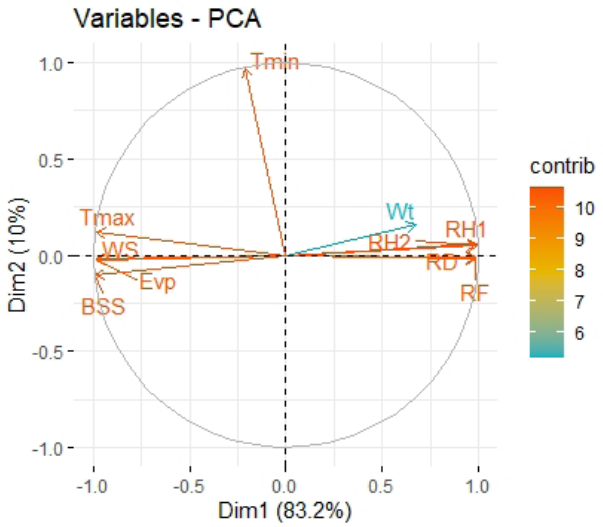

Fig. 2: Variable factor map obtained after PCA.

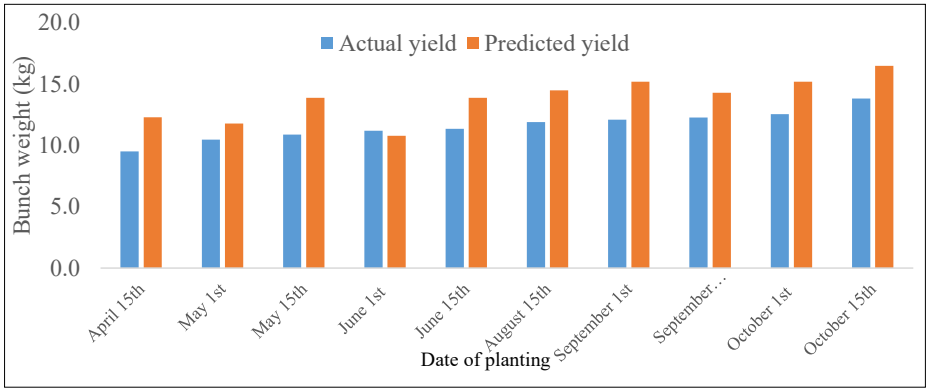

Fig. 3: Actual and predicted yield (bunch weight) of banana under different dates of planting

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