Citrus physiological disorders and their ameliorating control measures: A Review

Abstract

Citrus fruits are well known for their taste, flavour, aroma and fragrance, with rich vitamin C content. Fruits are rich in various nutrients, minerals and vitamins because of which they have the important role in pharmaceutical and nutraceutical industries. The citrus fruit cultivation experiences many challenges through biotic and abiotic stresses leading to occurrence of pest and diseases coupled with physiological disorders. The occurrence of pre and post-harvest disorders due to abiotic stresses and improper harvesting methods and unhygienic field conditions would lead to reduction in yield, fruit quality and commercial value of the produce and products. Improper harvesting and management in citrus fruits reduce the quality and appearance of the fruits. Pre-harvest disorders like granulation, fruit cracking, puffiness, superficial rind pitting, creasing and sunburn, and post-harvest disorders such as chilling injury, oleocellosis, rind staining, peteca, stylar end breakdown and stem end rind breakdown are the resultant disorders repeatedly noticed in citrus fruits. Maintenance of garden hygiene, flower regulation, water and nutrient management, *bahar* treatment, use of growth regulators and crop load coupled with canopy management would help in minimising the above disorders in citrus fruit crops.

Key words: Citrus, Pre and Post-harvest disorders, and Control

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1. Introduction

The genus *Citrus*of family Rutaceae are home to citrus fruits, which are prized for their high vitamin C content and aroma. These fruits also include nutraceuticals such as carotenoids (lycopene and β-carotene), limonoids, flavanones (naringins and rutinoside), vitamin-B complex and associated vitamins like thiamine, riboflavin, nicotinic acid/niacin, pantothenic acid, pyridoxine, folic acid, biotin, choline, and inositol (Ladaniya, 2008a). Citrus cultivation, according to global figures, covers 15.08 lakh hectares and produces 144.96 million tons annually.African continent leads in area under citrus occupying 65.43 % while Asia continent leads in production occupying 55.28 % of total world citrus production.China, Nigeria and India are the countries ranking top three positions in citrus production sharing the total world citrus production of 40.01 %, 28.70 % and 7.04 %, respectively. Indian citrus productivity (9.12 tonnes/ha) is quite similar to world citrus productivity (9.61 tonnes/ha), but far below from China (32.32 tonnes/ha), showing a great scope of research to increase the productivity of citrus (FAO, 2019).India's top producers of lime/lemon, mandarin, and sweet orange areGujarat, Madhya Pradesh, and Andhra Pradesh, in that order(NHB, 2018).

The malfunction of physiological processes of fruit tissues as a result of abiotic stresses such as temperature, relative humidity, moisture/water stress, chemicals, and excesses or deficiencies in nutrients can lead to physiological disorders. The problems induced by biotic factors like disease infections and insect pests are dissimilar from the disorders caused by abiotic causes (Ladaniya, 2008b).While some illnesses arise after harvest as a direct result of postharvest mishandling, others arise after harvest as a result of preharvest reasons such as mismanagement of irrigation water requirements, lack or toxicity of nutritional components, and other orchard management techniques. Granulation, fruit cracking, puffiness, superficial rind pitting, creasing, and sunburn are physiological disorders brought on by preharvest factors; postharvest factors result in chilling injury, oleocellosis, rind staining, peteca, stylar end breakdown, and stem end rind breakdown (Ladaniya, 2008b). Because of their detrimental effects on fruit quality and appearance, these illnesses lower the market value of citrus fruits. Below is a discussion of the genesis, causes, and preventative strategies of the major disorders affecting citrus fruit harvests.

2. Physiological disorders of citrus

2.1. Fruit cracking

A period of dryness followed by a lot of rain caused the tissue's moisture content to rise, which led to cracking. When the fruits reached their mature stage, cracking was more noticeable. There have been two kinds of fruit splitting identified: transverse and radial (longitudinal). Transverse splitting is less frequent than radial cracking. *Aspergillus*, *Alternaria*, *Fusarium*, and *Penicillium* are among the secondary bacteria that cause the broken fruits to decay, causing early fruit drop on trees. Just 10% of cracked fruits have transverse splitting; 90% of cracked fruits have radial cracks.

The incidence range for citrus fruit cracking is 10-35%, a major pre-harvest physiological disorder that has a negative impact on fruit quality and productivity. While some cultivars may have fruit cracking during the whole fruit growth and development phase, most citrus fruit cracking happens during the cell expansion or fruit maturity period. Citrus fruit cracking fluctuate according to fruit growth phases and variety. Citrus fruit can crack into three different patterns: flavedo-splitting, inner-cracking, and albedo-splitting (also known as fruit pitting or creasing). Cultivar features (Agusti *et al.*, 2003), rootstock (Storey *et al.*, 2002), peel thickness (Holtzhausen, 1981), peel hardness (Li *et al.*, 2011), fruit size and shape index, weather conditions like light, temperature and humidity (Gambetta *et al.*, 2000), mineral nutrients and growth regulators (Li *et al.*, 2016) are the factors that affect citrus fruit cracking.

Fruit cracking can be decreased by applying boron and potash fertilizers correctly, keeping the soil moist during the summer, and applying 2,4-D and NAA topically (Li and ChenJiezhong, 2017). In acid lime, spraying 40 ppm NAA after fruit set (around the third week of May) minimizes fruit cracking and enhances fruit size and weight. Fruit quality can be enhanced and fruit cracking can be decreased by applying 10-20 ppm of GA_3.

2.2. Granulation

Granulation is also known as vesicle drying, *kaosan* and crystallisation. This disorder is first reported by Bartholomew from Californiain the year 1934. The juice sacs of granulated fruits become hard, dry, get enlarged, grayish in colour with little juice content but the peel is not affected and remains fresh, thus it will results in insipid taste and markedly reduces marketability. The increase in textural rigidity during granulation is due to secondary cell wall thickening and lignification in the juice cells. The significant reduction in soluble sugars and organic acids in the juice sacs is the cause of this phenomenon (Shomer*et al.*, 1989; Chen *et al.*, 1994b, 2005).

Citrus fruits like mandarin (Dancy tangerine and Kaula varieties) and sweet orange (Hamlin, Mosambi and Blood Red) are more badly damaged than other forms of citrus (Singh, 2001; and Sharma and Saxena, 2004). The uneven proliferation of juice vesicles results in to irregular form of fruits and bulging of the affected area. A fraction of the pulp

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that is affected takes on a low TSS value and granular texture. Alcohol insoluble solids such cellulose, pectic compounds, hemicelluloses, starch and lignin also rose with the rise in granulation. Reduced pulp to rag ratio due to the majority of the juice turning into gelatinous substance and producing more rag (Zong *et al.*, 1979).

Citrus fruit granulation can be affected by a variety of factors, including species, cultivars(Singh *et al.*, 1985; Daulta and Arora, 1990), and rootstocks(Sandhu and Singh, 1989; Sharma and Saxena, 2004; Sharma *et al.*, 2006). Factors that play a role in citrus fruit granulation includetrees that are deficient in a variety of macro and micro elements (Awasthi, 1969); Large size of fruit (Sandhu and Singh, 1989; Sharma *et al.*, 2006); number of viable seed per fruit(Singh *et al.*, 1985); irrigation levels and frequencies (Raina and Lakhanpal, 1997; Sharma *et al.*, 2006); delayed harvesting (Chen *et al.*, 1994a; Burns and Albrigo, 1998; Sharma *et al.*, 2006); storage handling(Burns and Albrigo, 1998); more nitrogenous fertilizers; luxuriant growth after heavy pruning/fertilization; especially in coastal areas low temperature favours citrus fruit granulation; tree age (Young citrus trees are more affected than old citrus trees); heavy crop load and enzymes like peroxidase &superoxide dismutase(Sharma *et al.*, 2006).

The fruit granulation of citrus is controlled by early harvesting of fruits (Chen *et al.*, 1994a), hand pollination in pummelo (Chen *et al.*, 2005), applications of minerals such as $Ca(NO_3)_2$ (Harminder*et al.*, 1990, 1991), $FeSO_4$+ $MnSO_4$+ boron (Harminder*et al.*, 1990), $ZnSO_4$ (0.5%) and $CuSO_4$ (0.5%) or plant growth regulators such as GA_3 (Singh and Chohan, 1984; Cai *et al.*, 1989; Harminder*et al.*, 1990, 1991; and Chen *et al.*, 1995), NAA (Singh and Chohan, 1984; Harminder*et al.*, 1990; and Harminder*et al.*, 1991), 2,4-D at 12 ppm (Singh and Chohan, 1984; Harminder*et al.*, 1990, 1991), 2,4,5-T (Singh and Chohan, 1984), and ethychlozate (Cai *et al.*, 1989) solely or in mixture, spray of lime18-20 kg in 450 litres of water were reported effective in controlling granulation.

2.3. Chilling injury

Chilling injury is caused by the physical properties of the cell membrane due to changes in the temperature relationship between the cell membrane and the cell membrane lipids. The physical state of the cell membrane lipids is determined by the temperature relationship between cell membrane and structural proteins. Chilling injury occurs when the temperature of tropical or subtropical fruit is kept below 10-15^{o}C for a specified period of time. Citrus fruits are subtropical fruits and the injury developmentdepending on the species, variety and even within the same variety grown in different climate conditions. Limes, lemons andgrapefruitsare more sensitive to chilling injury compared to mandarins and sweet oranges. The most common symptom of citrus chilling injury is the peeling of the peel and the brownish colour of the peel(Wills *et al.*, 1998).

The modifications to the membrane's physical characteristics will impact the flow of lipids, ions, enzymes, and metabolites into and out of the cell. These alterations result in metabolic imbalances, which in turn cause cell death, the disintegration of cellular compartments, cell membrane disruption, and the appearance of chilling injury. Metabolic imbalances result in an increase in the respiration of injured tissues, which raises the energy needs of the cell to deal with disruptive processes. According to Eaks (1980), alterations in enzyme kinetics can cause metabolic imbalances that can result in the generation of harmful compounds like acetaldehyde. According to some theories, the presence of more free radicals during chilling causes more damage tochlorophyll content. Carotenoids can function as free-radical scavengers, the more of them there are in relation to chlorophyll, the more resistant to chilling. Better-coloured fruits are typically less vulnerable to damage from chilling (Bower

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et al., 1997). Mandarin cultivars Fortune and Nova's green fruits don't exhibit any pitting on the tree. Only non-green fruits (up to 90% were pitted after 4 weeks) developed pitting in cold storage (4°C). According to some research, fruit pigmentation influences the development of pitting susceptibility (Duarte and Guardiola, 1995).

Grapefruit’s susceptibility to chilling injury depending on the cultivar and the time of harvest. Oroblanco, the hybrid of grapefruit, exhibits greater resistance, whereas Red Blush and Star Ruby exhibit intermediate susceptibility after five weeks of storage at 4°C and one more week at 20°C (Schirra *et al.*, 1998). Marsh Seedless grapefruits in Florida have been found to be more susceptible to chilling injury during the harvest season. Grapefruits that are in season from February to March are more resilient to freezing than those that are in early or late season. When grapefruits are harvested from the outside canopy of a tree, the peel contains less proline and can be more vulnerable to chilling injury than grapefruits harvested from the inside canopy, which have a higher proline content (Purvis, 1981). In Nagpur Mandarins (Ladaniya and Sonkar, 1996) and Grapefruit (Singh, 1975), the suboptimal low temperature (4°C or below) resulted in chilling injury in the form of irregular, brown, pitted lesions and dull yellow, watery breakdown. At freezing temperatures, the carpellary membrane and albedo in lemons turn brown. These chilling symptoms developed in a specific citrus fruit at a specific low temperature (Smoot *et al.*, 1971).

Store citrus fruits at the lowest safe temperature to prolong their shelf life and prevent chilling injury. When fruits are kept at lessthanideal temperature, conditioning or sporadic warming is used to prevent chilling (chilling temperatures). It has also been reported that treating fruit with thiabendazole fungicides, PGRs, and wax coating, especially in grapefruit and mandarin cases, can somewhat lessen chilling injury (Grierson, 1971; Schiffman- Nadel *et al.*, 1977; Grierson*et al.*,1982; andLadaniya*et al.*, 2005). Application of 1-MCP at 50-500 ppm was reported to reduce peel pitting and chilling injury in Fallglo grapefruits and tangerines (Dou *et al.*, 2005).

2.4. Freeze injury

This is a prevalent issue in regions where citrus is grown at latitudes greater than or equal to 30°N and 30°S. Around the Mediterranean, freezes cause damage to citrus growing regions such as the U.S., China, Japan, and Latin America. Kinnow fruit has suffered damage in parts of Punjab and Rajasthan, India, where wintertime lows of below zero degree Celsius have persisted for extended periods of time. Whole citrus plants have been severely damaged by freezes, and frozen fruits have deformed inter-carpellary membranes with visible white hesperidin crystals in between segments. At the stem end, where moisture loss has occurred due to damaged membranes, and form the desiccated areas (Grierson and Hayward, 1959). Depending on the degree of damage, different countries have different policies regarding the acceptance of frozen fruit. Grade No. 1 oranges are grown in Florida shouldn't have freeze damage more than a 1/4th-in. slice at the stem end, but in California, a fruit's centre cut with 20% fruit damage are accepted (Grierson, 1986). Compared to the peel, the internal membranes and juice vesicles are more vulnerable to freeze damage.

2.5. Puffiness

Ponkan (*Citrus reticulata* Blanco) and Satsuma mandarin (*C. unshiu*) fruits of advanced maturity develop puffiness in the orchard itself, andfruits are more prone to puffiness. There is a space between the peel and the segments as the rind thickens and splits from the pulp (segments). Puffiness appears as fruit is stored for longer periods of time because of the high humidity. Puffing is extremely uncommon in sweet oranges, limes, and lemons. Fruit that has been cured prior to storage may have less puffiness (Murata, 1981).

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Kinnowmandarin fruits do not swell, but the majority ofNagpur mandarins develop a puffy appearance (Ladaniya*et al.*, 1990). Wei *et al.* (2000) investigated the physiological features and mechanism of puffing and discovered that cell membrane permeability increased and soluble sugar content decreased with an increase in puffiness percentage. By applying GA_3, spermidine, and Ca $(CH_3COO)_2$, it was possible to control puffiness by regulating membrane permeability and sugar content. Puffing can be reduced by harvesting at the right maturity stage and avoiding prolonged storage at high relative humidity.

2.6. Superficial Rind Pitting (SRP)

A dangerous condition that affects Shamouti oranges is called superficial rind pitting (SRP), which can occur on the tree as well. Three to five weeks after harvest, mostly during shipping and marketing, SRP symptoms appear. The production of ethylene raises the frequency of disorder. Compared to healthy fruits, fruits with SRP had a lower rind potassium content. The incidence of SRP is decreased and leaf potassium concentration is increased when potassium fertilizer is sprayed on trees. Additionally, storage at 5°C inhibits SRP development. Good control is achieved by combining postharvest low-temperature storage with preharvest potassium spray. The incidence of SRP in Shamoutiorange appears to be influenced by soil and climatic factors. Tamim *et al.* (2000) proposed the theory that a potassium deficit causes bio-membrane dysfunction, which results in water loss, cell necrosis, and collapse, ultimately leading to SRP. If wax and potassium are applied to fruit in the packing house, the postharvest appearance of SRP can be minimized.

2.7. Rind Staining

Citrus fruits get a brown or reddish-brown discoloration on the areas that sustain minor abrasions during harvesting, packing, and transit. Alferez *et al.* (2003) found that compared to fruit harvested from orchards not impacted by natural rind breakdown, navel orange fruits harvested from orchards with a high incidence of rind breakdown on the tree were more likely to develop rind staining after storage, had higher ethylene production, and had lower flavedo and albedo water potential at harvest. When 'Navelina' orange fruit was transferred from 30 to 20 or 12 degrees Celsius, it did not acquire rind staining, regardless of whether it was stored at low (45%) or high (95%) RH. In contrast, even though the rate of weight loss was comparable to that of fruit whose storage temperature was lowered, fruit kept at a constant temperature (20°C) saw an increase in the incidence of rind staining upon transfer from 45 to 95 percent relative humidity (Alferez *et al.*, 2003). The mature fruit must be handled carefully in order to prevent rind staining. Rind staining rises with maturing peel, and GA_3 applications might help lessen this condition.

2.8. Kohansho

Pitting on the fruit's periphery, stem end, or stylar end are signs of Kohansho. There are discoloured and sunken spots. This disorder is primarily seen in Hassaku (*C. hassaku*)grows in Japan. Hasegawa and Iba (1981) found that in fruit affected by Kohansho, the sugar content decreases while the peel's respiration and ethylene evolution increase. The cause of Kohansho in Navel orange fruits is low temperatures. In stored Navel orange fruits, the incidence is reduced by shading to lessen light intensity. It has also been noted that there is an annual variation in the disorder's incidence when fruits harvested from the same groves are stored. The incidence on the tree tended to increase with lighter crop loads. The majority of spots were on the stylar ends of the fruit. When stored at 10°C, even fruits that were harvested in October and November but had not been exposed to low temperatures started to exhibit signs of injury (Chikaizumi*et al.*, 1999). Thiabendazole (TBZ) treatment and

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individual seal-packaging with LDPE film are efficient ways to lower the incidence of this disorder.

2.9. Peteca

Peteca, a postharvest physiological condition in lemons, usually manifests from harvest until cold storage and is linked to the collapse of an oil gland. Rind pitting, sinking of rind, and darkening of oil glands are signs of peteca (Cronje, 2007). It appears that the name *petecchia*, as it was known in Italy, was taken from the incidence of this disorder in lemon fruit that was documented in the USA as early as 1924 in lemon fruits shipped from Italy (Fawcett, 1936). Peteca's initial symptoms appear three to five days after harvest and appear before the fruit is placed on the packline. It is characterized by the darkening of a single oil gland; if the flavedo is removed, the brown oil gland with the discoloured albedo tissue directly below can be seen. The rind tissue around the collapsed oil gland sinks after a few days, and other nearby oil glands may also collapse. Although fruit with a yellow rind typically has a sunken lesion that is easily visible, this collapse of the oil gland can occur in both green and yellow fruit (Cronje, 2007).Lemon fruit's vulnerability to this disorder has been linked to a number of pre and post-harvest variables. Low rainfall in the three months leading up to harvest in South Africa, combined with cold and wet conditions (significant variations in day and nighttime temperatures) in the run-up to harvest, have been observed to lead to a higher incidence of peteca. This is consistent with the notable rise in peteca incidence that has been reported in Tucumán following a sudden drop in temperature in the week before harvest (Torres Leal, 2004). The same circumstanceshigh relative humidity and low temperaturewere noted as harmful by Wild (1991), and Undurraga*et al.* (2006) found that rainfall on lemons during harvest was leading to the peteca's development in Chile. The frequency of this disorder is increased due to increased brushing time. Compared to carnauba wax emulsion, waxes with a polyethylene base cause more Peteca. This disorder grows in extremely humid environments. This disorder has also been linked to nutritional imbalance. High levels of oxalate in the leaves are thought to be the cause of the Peteca disease that affects lemons in Lebanon. Elevated levels of oxalic acid in the leaves were caused by increasing nitrogen levels and, to a lesser extent, moisture stress. This disorder is further exacerbated by high calcium and low available phosphorus levels in the soil (Kahalidy and Nayyal, 1974).

Peteca, and calcium imbalances in the rind have been linked (Khalidy*et al.,* 1969), and Storey and Treeby (2002) have looked into the role of calcium content in the rind as well as calcium oxalate crystals. They discovered that peteca impacted rind's had 23% more calcium and 30% less boron. Degreening and storing for three to five days after harvest reduced the frequency of peteca. When lemons with yellow hues were stored at 3°C, the incidence of peteca was higher than when "silver" coloured fruit was stored at 3°C and 7°C (Undurraga*et al.,* 2009).

2.10. Red Blotch or RedColoured Lesions

There have been reports of superficial wounds on flavedo in degreened Florida citrus, with a reddish colour in the lesion and the surrounding peel (Grierson, 1986). The formation of lignin occurs during wound healing, and coloured polyphenolic compounds are thought to be the cause. There have been reports from Israel of a comparable physiological disorder in degreened lemons (Cohen, 1991). It is thought that an oxidative enzyme system is the cause. The red blotch was lessened by degreening at 30 °C and dip treating with antioxidants at 2500 ppm.

2.11. StylarEnd Breakdown

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Stylar-end breakdown manifests as watersoaked, dullcoloured patches at the lime nipples and, occasionally, as white mycelium on the fruit epicarp. Tahiti or Persian limes break down at the stylar end when handled roughly. Fruit susceptibility is influenced by temperature, humidity, turgor pressure, and fruit size during storage. Big fruits are more likely to have this condition. Stylarend breakdown is caused by high temperatures during pre-harvest periods, especially after rainy events. Numerous studies looking into the origins of this disorder came to the conclusion that the rupture of the juice vesicles and the rind's destruction of chlorophyll determined the affected area. Subsequent analysis showed that the rupture of the juice vesicles and the juice's passage into the rind were the root causes of the distinctive symptom at the stylarend. The pathogenicity tests outcomes showed that *G citri-aurantii*was caused the wet spots at the stylar end. Stylarend breakdown is followed by secondary infection by *Penicillium, Aspergillus,* and *Colletotrichum*.

2.12. Stem-End Rind Breakdown (SERB)

SERB affects the majority of citrus fruits, and also known as aging. During storage, the rind around the stem end wilts and dries down in sunken, uneven brown areas. Though it can also happen on tangelos and grapefruit, SERB is most severe on oranges and Temples. It may show up in the orchard itself when the fruit is overripe. Fruit may also be vulnerable to this condition if there is an nitrogen and potassium nutritional imbalance in the orchard (Grierson, 1986). The characteristic of SERB is a 2 to 5 mm ring of unaffected tissue immediately surrounding the stem (button); the cuticle of that area has a thick layer of natural wax and is devoid of stomata. When it comes to small and vibrantly coloured fruit, SERB is more prevalent and severe. Fruit with thinner skin that is cultivated in humid climates, like Florida, is generally more susceptible to SERB than fruit with thicker skin that is grown in arid climates. These drying conditions are caused by things like packing delays, keeping the fruit in hot, humid conditions, and moving a lot of air around it. Overbrushing during packing promotes the development of SERBs and increases water loss. When fruit is harvested from water-stressed trees as opposed to non-stressed trees, SERB has reportedly been found to be more severe. Fruits exhibiting severe symptoms taste bad. Fruits that are affected are vulnerable to other fungi or stem-end rot. Seasonal variations in incidence mean that fully ripe and mature fruit is more likely to have it; therefore, harvesting and handling should be done quickly and carefully (Ritenour and Dou, 2003).

In Nagpur mandarins, the processes of curing (keeping fruit for one to two days after harvest), brushing, and packing without polyethylene liners combined to cause browncoloured sunken spots with breakdownof collar (Ladaniya and Sonkar, 1997). Compared to the rest of the fruit surface, the Nagpur Mandarin's raised collar is more vulnerable to handling abuse. The amount of disorder can be reduced by carefully harvesting and handling the fruit, moving it quickly to the packing house, keeping it at 80-90% RH, and using minimal brushing (keep brush speeds below 100 rpm) on the packing line. Lemons and limes are the exception; they must be kept in the shade of the orchard for two to three days in order to cure.

2.13. Oleocellosis

The oleocellosis is brought on by the mechanical injuries that harm the oil glands and release the toxic oil. Insect attacks, hail, bruises, and fruit that has been damaged coming into contact with unharmed fruit are additional causes of this disorder. The incidence of oleocellosis is primarily found in sweet oranges, lemons, and limes (Montero *et al.*, 2012). All citrus fruits can develop oleocellosis, but green fruits that are harvested early have a higher risk of developing the condition. Oil spotting can occur when limes, lemons,

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mandarins, and navel oranges are harvested early in the morning and then immediately transported. Oleocellosis is caused by phytotoxic oils (terpenes) that are released into the environment and harm nearby living cells. The primary causes of this are bruisesduring harvest and rough handling during packing and shipping. The rupture of oil glands causes the surrounding epidermis to necrotize, which causes the formation of irregularly shaped yellow, green, or brown spots. The spots are distinguished by the prominence of the oil glands on the skin due to a slight sinking of the tissues between them. Elevated temperature causes oleocellosis to manifest. Studies have been conducted on the physiological and biochemical traits that are linked to citrus oleocellosis. The onset of oleocellosis appears to be correlated with the concentration of antioxidant compounds. Flavedo with a natural rind spot in *Citrus junos* fruits had lower antioxidant activity than flavedo without it.Flavedo with rind spot had lower total tocopherol contents than sound flavedo, with approximately 8.2 mg/100g of α-tocopherol and 1.0 mg/100g of γ-tocopherol, respectively, at 7.2 and 4.5 mg/100g, according to Sawamura et al.,(1988). The severity of rind-oil spot is linked to90 days of storage at 10°C with low relative humidity, higher rates of CO_2 and ethylene production. The degree of rind-oil spot was also correlated with total non-structural carbohydrate content (Kanlayanarat*et al.,* 1988).

Temperature had an impact on the onset of oleocellosis symptoms in Washington Navel oranges, with the disorder developing more slowly at temperatures below 10°C. The rate and degree of the rind blemish's colour development have also been demonstrated to be influenced by other environmental factors, such as the concentrations of oxygen and carbon dioxide. The degree of sunlight exposure of the tree also made the rind more vulnerable to the oil spot. It has been demonstrated that artificial wax coatings can reduce oil damage by up to 35%. The tape method of sensitivity testing shows that variations in the development of oleocellosis are depends on the peel's tolerance to the released oil as well as variations in the pressure needed to break the oil glands (Wild, 1998). Fruit is less turgid and susceptible if it is harvested in the afternoon and kept in sheds for one to two days prior to transportation. There has also been notable variation in the incidence of oleocellosis on fruit harvested from various orchards, suggesting that the degree of rind blemish is determined by the harvesting process.

2.14. Creasing

To get good market values and profit, some growers go for the late harvesting of mandarin and sweet orange by storing fruits on trees only, but there will be the incidence of physiological disorder called creasing due to late harvesting. These fruits will have the poor post-harvest storage capacity and poor transportability due to decreased firmness.Creasing disorder is also known as puffiness. This disorder is characterised by presence cracks in cell layers of albedo tissue of peel, depressions on rind and healthy areas of fruit becomes bulky with loss of turgor pressure, cell wall collapse, pectin degradation and promotion of pectin methyl esterase activity of albedo tissue (Agusti*et al.,* 2002). The creased fruits are large in size with higher water content, lower coarse rind grading, thinner peel, higher nitrogen and potassium content in the fruit and lower calcium content. Cultural practices (mineral nutrition), climatic (light, temperature, humidity), genetic and endogenous factors are the cause of creasing disorder (Agusti*et al.,* 2002; Li Juan and Chen Jiezhong, 2017; Sallato*et al.,* 2017). The nutrient imbalances, specifically low Ca and K and high P, warm and humid climatic conditions, irregular water supply, and heavy crop loads are the reasons for fruit splitting or albedo breakdown in citrus fruit (Cronje *et al.,* 2013). The creasing disorder is

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positively correlated with K/Ca and Mg/Ca ratios of fruit and negatively correlated with the calcium content in pulp, rind, albedo and flavedo tissue of fruit (Storey *et al.*, 2002).

The higher pectolytic activity and higher water soluble pectin content with earlier senescence of albedo tissues (Monselise*et al.*, 1976), and decrease in pectin and hemicellulose content of peel less than 70% of cell wall polysaccharides cause the incidence of this disorder (Roberto *et al.,* 1989). The activity of an enzyme uronic acid oxidase at harvest is responsible for incidence of creasing. The nutrient analysis of fruit relieved that molybdenum as a co-factor in synthesis and activation of an enzyme uronic acid oxidase. The lack of pectin and ureide formation is the cause of creasing incidence (Bower, 2004). The higher activity of enzymes like polygalacturonase, cellulase and pectin esterase in the cell walls of peel tissue of citrus fruit (Li *et al.,* 2009). Endogenous levels of ethylene were significantly higher in the creased fruit compared to normal fruit (Hussain and Singh, 2015). Postharvest creasing incidence was seen in more mature fruits with high pectinesterase activity when stored for 2 weeks at 21 °C compared to less mature fruit with average pectinesterase activity (Nagy *et al.,* 1985).

The creasing disorder is controlled through foliar application of GA_3at the concentration of 25 mg L^{-1} prior to colour break (6-8 weeks before the normal harvest season) delayed the colour change of the flavedo and prevented peel puffing. In GA_3 treated fruits higher fruit firmness, reduced peel thickness and weight, and loss of juice in mature fruits was also retarded. It will be helpful in extending harvesting season without affecting internal fruit quality (Pozo*et al.,* 2000). Application of GA_3 at fruit size of 30-40 mm or just prior to colour breaking stage of fruit will reduce the incidence of creasing disorder. Gibberellins make long term formative effects in albedo tissue, delay the senescence of albedo tissue and increase the compactness of albedo tissues (Agusti*et al.,* 2002). The combination of fruit thinning and GA_3application, sufficient nutrition application (Ca, K, and P) and consistent irrigation are the practices to reduce fruit creasing incidence (Cronje *et al.,* 2013).

2.15. Rough skin disorder

One major condition that lowers yield in young mandarin orchards (6-12 years old) and senile orchards is rough skin disorder, which is brought on by excessive potassium application or availability. Compared to regular fruits, the disordered fruits have a thicker rind, are larger in size, and an improper shape (Ashok *et al.,* 2006; Erner*et al.,* 2002;and Srivastava, 2013). Rough skin fruits have a larger core diameter, lower juice percentage and TSS. At harvesting, fruits arestill green with yellow coloration in patches,and improperly matured. As a result, the mandarin growers will suffer financial losses since these fruits will not bring in the market values.

2.16. Sunscald

Sunscald is an important disorder of citrus fruits. This disorder could occur at phenological stages in *Ambebahar*(spring flush occurring in January-February)crop. First, it may occur during the young fruit development stages in the months of April-May due to hot and dry weather, high temperature and low relative humidity coupled with water deficit stress; second time it could occur during monsoon re-growth in the months of June to September due to long dry spells with supra-optimal maximum temperatures with high relative humidity and third time it usually occurs during post-monsoon October month due to

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rising afternoon temperatures, high relative humidity, fewer or no rainy days. The severity of disorder is more in heat and drought stressed plants. The disordered fruits are with improper colour development *i.e.* sun exposed surface is yellow/brown in colour with ruptured oil glands and remaining part unexposed to sun remaining green in colour. The fruit peel of sun scalded fruit becomes hard with increased firmness. Fruit segments become dried and granulated with less juice content, reduced TSS and titratable acidity. Further, when these fruits pass through rainy, humid and hot weather, the secondary fungal infection and rotting of fruits is observed at sun scalded area. Thus, sunscald incidence in citrus fruits causes significant economic loss to growers by reducing the marketable yield and quality characteristics mainly during September-October months. Kaolin and calcium carbonate spray, paper bags and shade nets are used to manage the sunscald incidence and to improve the quality characteristics of fruits. But the use of paper bags and shade nets are not convenient to use and practice.

Kaolin is a white coloured non-porous, non-swelling, low-abrasive, plate-shaped, fine-grained clay and natural aluminosilicate mineral ($Al_4Si_4O_{10}(OH)_8$) with constituent of kaolinite. It is easily disperses in water and is chemically inert over a wide pH range. More than 99% pure kaolin with a brightness of >85% is obtained by water processing. The present particle film technology is based on kaolin with important feature of the light reflection and important characteristics of effective particle films are chemically inert mineral particle, particle diameter should be < 2 μm, it should create a uniform film and spread, porous film that does not interfere with gas exchange from the leaf, transmits photosynthetically active radiation (PAR) but excludes ultraviolet (UV) and infrared (IR) radiation to some degree, alters insect/pathogen behaviour on the plant, and can be removed from harvested commodities easily (Glenn and Puterka, 2005).It is applied in different fruit crops mainly to minimize fruit sunburn, to improve yield and fruit quality (Kerns and Wright, 2000; Colavita*et al*., 2011 and Alvarez *et al*., 2015).

Application of calcium types *i.e.* calcium carbonate ($CaCO_3$) or calcium based fertilisers will give good sun protection quality to fruit crops (Narayanand Nisha, 2017). Glenn *et al.,* (2002) reported that use of plant protectants and $CaCO_3$ on Crimson Seedless grapevines will makes less prone to sunburn damage than untreated ones and by reducing fruit temperature and reflecting UV radiations. Abd El-Naby *et al.* (2020) observed that calcium silicate treatment which improved the vegetative growth characteristics, macro and micro elements of leaves, and fruit physical and chemical characteristics of Valencia orange trees compared to control.

2.17. Fruit drop

The two main issues with all commercial citrus fruit varieties are low fruit set and heavy fruit drop. The fruits keep falling off at different phases of their development. It is sufficient to produce a normal crop even if only 4-6% of the flowers set. In citrus fruits, there are three stages to fruit drop. In first wave aborted pistils tend to drop soon after fruit set. June drop is the second wave of fruit drop that happens as summer (May-June) approaches. It is caused by a desiccating wind, low atmospheric humidity, low soil moisture, and high temperatures. Just before harvest, there is a third wave of fruit drop, which causes citrus growers to suffer a significant financial loss. Fruit drop intensity can vary depending on the

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variety, climate, soil type, etc. When the fruits reach the marble stage, the fruit drop is at its most noticeable. A major factor in fruit drop is the hormonal state of the developing fruit. Fruit drop is closely linked to endogenous auxin reduction and stress-induced ethylene signalling. Fruits with fewer seeds usually ripen sooner.

Auxins such as 2,4-D and NAA, applied topically at concentrations of 10-20 ppm in April-May and August-September, regulate the physiological fruit drop. When a dicot crop is already present in the orchard as an intercrop, the spray shouldn't be applied (Anonymous, 2004). When NAA 20 ppm is applied foliarly to Nagpur mandarin at the pea and gravel stages, fruit retention is increased by 45 percent and pre-harvest fruit drop is decreased (Verma *et al.,* 2018).

2.18. Citrus dieback/decline

In most of the citrusgrowing nations (USA, Mexico, Brazil, Argentina, South Africa, Iraq, Iran, Turkey, India, etc.), citrus dieback/decline is a widely publicized disorder. It is said to result from a multitude of factors, usually acting in concert. It is not a particular illness in India, but rather a symptomatic expression of numerous disorders in the plant (Dhatt and Dhiman, 2001). According toKanwar *et al.*(1965)citrus decline is caused by soil conditions. In India, citrus decline can be attributed to improper and inadequate soil nutrition. Compared to the healthy tree, the declining tree has lower nutrient levels and a higher incidence of pre-harvest fruit drop (Saini *et al.,* 2004). After five to six years of excellent growth, citrus plants typically begin to decline, showing a gradual decrease in yield and vigour. The plant's age increases the magnitude of the decline, and after 15 to 20 years, the affected plant becomes unprofitable. Usually, a declining tree does not die; instead, it just stops producing the fruits. The main signs include the tree growing more slowly than usual, chlorotic leaves appearing, sparse foliage, twig dieback, and a generally sickly appearance. In the end, this caused the tree to die. Compared to other citrus trees, the decline in mandarin trees has been reported to reach 40-60% of the total.

Shallow soil (less than 45 cm deep), hard pan in the subsurface, moisture stress, poor soil drainage, higher soil pH, higher EC value of the soil and irrigation water, low soil organic matter, nitrogen deficiency in the soil and plant, low levels of endogenous hormones, zinc deficiency, stock-scion incompatibility ('Fairchild' mandarin on Macrophylla), pest and disease incidence, and nematode damage are the factors contributing to the citrus decline. The integrated approach based on the associated factors is the only thing we need to follow; there are no specific control measures. The use of virus-free planting material, careful rootstock selection, appropriate site and soil selection, prudent irrigation, manuring, timely nutrient application, hormonal applications, use of organic manures, integrated pest and disease management, and nematode control are all beneficial in extending the life of trees.

2.19. Frenching or Foliocellosis or Mottle leaf

Frenching, also known as foliocellosis or mottled leaf, is a significant citrus disorder that primarily results from a zinc deficiency (Sharma, 2005). Its hallmark symptoms include small leaves on terminal growth, irregular and chlorotic leaf spots, and severe twig dieback. A fruit's size is also reduced, and its colour is frequently lighter. Fruits could be asymmetrical. Fruit has a low acid and vitamin C content, is woody, dry, and insipid in taste (Elavarasan and Premalatha, 2019). Zinc sulphate applied topically at a rate of 0.5 percent is used to treat this disorder (Sharma, 2005).

3. Conclusion

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Citrus fruit crops being the major concept of fruit industry under the horticulture have become economically and culturally important in India. Their significance in daily diet, pharmaceutical and nutraceutical industries have been made citrus fruits of commercial importance. Citrus fruit cultivation in India has experienced many of the problems through climate change, pest and diseases occurrence and physiological disorders leading to the reduction in physical and chemical quality of the fruits. Maintenance of hygiene inthe orchards, canopy management, water and nutrient management, in association with adoption of recommended package of practices for successful cultivation would help in reducing the occurrence of physiological disorders. Even the use of planting material grafted on resistant rootstocks would take care of the disorders. The application of cross protection technology while propagating the planting material is promising tool to minimise the viral invasions leading to physiological deviation of the plant system which results in physiological disorders. Successful citrus cultivation depends on the efficient management of the pests, diseases and physiological disorders.

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