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Physiological disorders of selected *Citrus* fruit species in Sri Lanka and their effect on fruit quality

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ABSTRACT

Purpose: This study was conducted to identify the physiological disorders and their symptoms of selected *Citrus* fruit species (*C. sinensis*, *C. limon* and *C. crenatifolia*). Furthermore, it was aimed to determine whether physicochemical and sensory properties were affected by physiological disorders. **Research method:** *Citrus* fruits with physiological disorders were observed separately for visible changes and characters were recorded and photographed. Moreover, *Citrus* fruits with physiological disorders were analyzed for physicochemical and sensory properties. **Findings:** Many physiological disorders were recorded from three *Citrus* fruit species including chilling injury, sun burn, stem-end rind breakdown, oleocellosis, rind disorder, puff and crease, granulation, wind injury, peteca, fruit splitting and fruit cracking. Based on the overall result of sensory analysis, it can be concluded that most of the physiological disorders in studied *Citrus* species appear on the peel but not adversely affect the edible internal portion of the fruits. Physicochemical properties of *C. limon* are not adversely affected by physiological disorders whereas *C. sinensis* and *C. crenatifolia* are affected by physiological disorders. **Limitations:** Availability of selected *Citrus* fruit species throughout the year is limited due to their seasonality. **Originality/Value:** This study provides novel information about the physiological disorders of some *Citrus* species in Sri Lanka and other parts of Asia and a future potential exists in controlling these disorders to provide healthy and quality fruits to the market.

INTRODUCTION

Citrus is the largest genus in the family Rutaceae and is the most traded horticultural product in the world (Turner & Burri, 2013). Most of the *Citrus* fruits are highly preferred as fresh juice and as a flavor enhancer in food, indicating high economic value. Due to the delicious taste and nutritional value, they have become one of the most desirable fruits in the international market as well as local market. *Citrus* fruits have higher contents of nutrients such as vitamin A and C, minerals, sugars, amino acids and carbohydrates with beneficial properties for health such as antioxidant and anticancer (Herath et al., 2016; Paul & Shaha, 2004).

Citrus sinensis (Green cultivar is locally known as Pani dodam) is considered as one of the most important fruit crops of *Citrus* genus due to its sweet taste and many benefits such as multifold nutrition and medicinal values. *C. sinensis* is more popular among consumers as a fresh juice due to its juicy nature (Shravan et al, 2018). *Citrus limon* (Lemon) is commonly used as a food ingredient in both home and commercial recipes and is valued for its tart, tangy, and fresh character. Further, lemon is an excellent preventative medicine and has a wide range of uses in the indigenous medicine. The zest is used as a major source of commercial essential oil and aroma compounds (Chaturvedi & Shrivastava, 2016). *Citrus crenatifolia* (locally known as Heen naran) which is native to Sri Lanka, has a wide range of medicinal properties and used for treatment of vomiting, nausea and liver diseases.

Due to the failure of some physiological processes of the fruit tissues and because of biotic and abiotic stresses, *Citrus* fruits are subjected to different types of physiological disorders such as chilling injury, stem-end rind breakdown (SERB), peel pitting, freeze injury, granulation, puff and crease, sunburn, and fruit cracking. Some physiological disorders such as freeze injury, granulation, puff and crease, sunburn, peteca and fruit cracking are preharvest disorders associated with climatic factors and management practices occurring in fruit orchards (Dreistadt, 2012; Ladaniya, 2008). These physiological disorders mostly affect the rind but do not affect the edible internal portion of the fruit. However, these physiological disorders decrease nutritional quality and marketability of fruits since external appearance is the primary specification which is used to evaluate the quality of fresh *Citrus* fruits (Vera-Guzman et al., 2017).

The amount of *Citrus* fruits affected by physiological disorders has been reported as 60% of total production in the world (Agusti, 2001). Most physiological disorders are responsible for loss of quality and consumer acceptability as it results not only in direct quantitative loss, but also loss in appearance (wilting and shriveling) and softening. Moreover, visual quality of *Citrus* fruits is highly affected by these disorders due to the changes in peel color (Palou et al., 2015). These physiological disorders affect the nutritional properties of *Citrus* fruits such as vitamin C, soluble sugars and minerals. Most of the physiological disorders alter the physiochemical properties of *Citrus* fruits such as titratable acidity, pH and ascorbic acid content. These compositional changes also affect the sensory properties such as taste and flavor of fruits (Barrett et al., 2010; Mditshwa et al., 2017).

By taking the above information in to consideration, this study was carried out to identify the important physiological disorders of selected *Citrus* fruit species and their symptoms. Furthermore, major physicochemical properties and sensory properties were tested in physiologically disordered *Citrus* fruits by comparing with healthy fruits.

MATERIALS AND METHODS

Assessment of physiological disorders of *Citrus* fruits

Citrus fruits (*C. sinensis*, *C. limon* and *C. crenatifolia*) with observable physiological disorders were collected from local markets located in Kegalle, Kandy and Gampaha districts in Sri Lanka. Selected fruits were observed separately for visible changes in the fruit peel and compared with control fruit samples. The characters were recorded and photographed.

Assessment of sensory properties

Sensory evaluation was carried out by providing healthy (control) and physiologically disordered *Citrus* fruit samples with three replicates to a 10-member, un-trained sensory panel along with a questionnaire to evaluate flesh color, aroma, texture, taste, flavor and overall acceptability. Each sample was presented to the sensory panel in a random order to evaluate the samples by assigning scores ranging from 1-10, where Excellent (9 – 10), Good (6 – 8), Fair (4 – 5) and Poor (1 – 3) respectively (Siriwardana et al., 2017).

Assessment of physicochemical properties

Three replicates of *Citrus* fruit samples with physiological disorders and control fruits were analyzed for physicochemical properties. Total soluble solids (TSS) (°Brix) of the juice of fruit pulp were determined using a Hand-Held Refractometer (ATC-1E, ATAGO Co. Ltd., Japan). pH of the sample filtrate was measured using a Portable pH Meter (PC 510, EUTECH Instruments, Singapore). Fruit firmness was determined using a Fruit Firmness Tester (FT 011, QA Supplies and Italy). Ascorbic acid concentrations of juice samples were determined by titrating 5 mL of fruit juice against a standard potassium iodide/iodine (KI/I2) solution in the presence of starch as the indicator (Herath et al., 2016; Siriwardana et al., 2017).

Statistical analysis

Statistical analysis of the results was carried out using MINITAB 17 statistical software. Data obtained for physicochemical properties were analyzed using One-way ANOVA and mean separation was done using Tukey's multiple comparison tests. Kruskal Wallis non-parametric test was used to analyze data with respect to sensory properties (Siriwardana et al., 2017).

RESULTS AND DISCUSSION

Assessment of physiological disorders in selected *Citrus* species

Physiological disorders observed in Citrus sinensis (Green cultivar)

Many physiological disorders were recorded in *C. sinensis* such as chilling injury, sun burn, SERB, oleocellosis, peel pitting, puff and crease, wind injury and granulation. When considering the chilling injury in *C. sinensis*, symptoms were visible when fruits were taken to warmer temperatures from chilling temperatures. Furthermore, dark brown patches and superficial scald like symptoms with small pits on the flavedo were visible (Fig. 1-A). According to the findings of Lindhout et al. (2005) and Maria and Lorenzo (2006), similar symptoms have been observed in Navel orange (*C. sinensis*) as well. However, high damaged tissue of Navel orange become extremely sunken, hard and brown with a distinctive honey-like odor, which was not observed during the present study.

According to the present study, *C. sinensis* which were subjected to sun burn incidence formed necrotic blotches on the skin and the side exposed to the sun indicated yellow patches and brown, leathery areas (Fig. 1-B). As stated by Verreynne and Merwe (2011), similar symptoms have also been observed in Satsuma mandarin (*C. unshiu*). Further, burn like localized areas has been developed at spots facing high solar radiation.

SERB symptoms in *C. sinensis* showed collapse of rind tissue around the stem-end of the fruit with a narrow ring of unaffected tissue immediately around the stem button. Furthermore, affected area was circular in shape and became dark and sunken in *C. sinensis* (Fig. 1-C). As described by Dou et al. (2000), these similar symptoms have been observed in Valenica orange (*C. sinensis*) as well and SERB is a result of excessive dehydration of the flavedo around the stem end of *Citrus* fruits.

In oleocellosis subjected *C. sinensis* fruits, necrotic tissue and irregular shaped yellow, green, or brown spots were observed and the affected areas were initially yellow and gradually turned in to greenish brown sunken spots on the flavedo (Fig.1-D). These observations of the present study are compatible to a greater extent with previous observations made in Navel orange by Knight (2002) such as the presence of necrotic tissue on the flavedo. However, affected areas have retained green color following degreening and later become darkened collapsed cells in Navel orange.

During the present study, peel pitting disordered *C. sinensis* fruits displayed numerous tiny and sunken brown color spots on the whole fruit surface area. Further, collapsed areas of flavedo and part of albedo turned brown with time (Fig. 1-E). However, results of the present study are not compatible with Alferez et al. (2005), since sunken areas of flavedo (pits) which were eventually spread, turned bronze in color and became necrotic in severe cases in peel pitting in Navel orange (*C. sinensis*).

In puff and crease disordered *C. sinensis* fruits, fruit peel became thick and separated from the pulp and the damaged tissue had a dry texture. It was observed as a slightly depressed area on the fruit surface (Fig. 1-F). Results of the present study are in agreement with the observations reported by Storey et al. (2002) on puff and crease disorder of both Navel orange and Velanica orange. Some portions of the rind surface were observed to be inflated while other areas were seen as indented and albedo was separated from the outer surface of the fruit segments.

During the present study, a cloudy white to grey appearance and scabby scars were observed in some parts of the flavedo in green *C. sinensis* which have been exposed to wind injury (Fig. 1-G). Further, damaged tissue had a rough and dry texture. A previous researcher, (Dreistadt, 2012), noted certain different symptoms in grapefruit *(C. paradisi*) which were subjected to wind injury such as pale to brown scabby scars on flavedo which expanded as the fruit enlarged during growth.

In granulated fruits of *C. sinensis*, enlarged and hardened juice sacs were apparent at the stem end and gel formation was also observed within the juice vesicles (Fig. 1-H). Previously similar symptoms have been observed in Valenica orange as well (Ladaniya, 2008). Further, fruit weight, pulp percentage and extractable juice percentage have been reduced while peel percentage was higher in granulated fruits than in control fruits.

Physiological disorders observed in Citrus limon

In *C. limon* fruits, six physiological disorders were observed including chilling injury, oleocellosis, peteca, fruit splitting, rind disorder and puffing. Symptoms of chilling injury disorder were apparent after taking the fruits out of refrigeration temperature into warmer temperatures. Further, small sunken lesions with a slight darkening of the peel were visible and when the fruit was cut in half, a discoloration could be seen in the albedo (Fig. 2-A). However, these observations are not in agreement with Underhill et al. (1995). They reported large sunken lesions and browning of tissue with localized discoloration around the oil glands in Eureka lemon (*C. limon*) as chilling injury symptoms. It is worth while noting that certain cultivars of the same species of fruit may display different and severe disorders.

When considering the oleocellosis disorder in lemon, greenish-yellow areas were visible on yellow background of the flavedo. Moreover, the affected areas were irregular in shape and necrotic tissues were visible adjacent to these areas in some parts of the fruits (Fig. 2-B). Results of the present survey are in agreement with the observations reported by (Dreistadt, 2012), such as greenish-yellow, irregular areas on yellow background of the flavedo which is a result of the oil released after the mechanical rupture of the oil glands.

According to the results of peteca disorder of *C. limon* fruits, small green color patches and round depressions were observed which became brownish with time (Fig. 2-C). However, Dreistadt (2012) has reported that round depressions on the flavedo, that became sunken, discolored or slightly brown spots with necrotic tissue and collapsed cells in coastal lemons (*C. limon*).

Fruit splitting was observed in mature and ripe lemon fruits with a brown stripe which leads to a visible crack on the fruit peel. Further, tissues adjacent to the cracked surface were severely damaged (Fig. 2-D). During a research conducted on Meyer lemon (*C. limon*) by Li and Chen (2017), it has been reported that peel splitting has occurred in dry spells followed by heavy rains. During this time, peel expands rapidly when the excess water enters the ripening fruit and this expansion results in the splitting of lemons with weaker rinds.

In the present study, formation of brown pit-like depressions on the peel and discoloration of the skin was evident in rind disordered *C. limon* fruits. Further, pits were bronze colored and gradually became necrotic in severe cases of rind disorder (Fig. 2-E). These observations agree to a considerable extent with previous observations reported by Assimakopoulou et al. (2009), in rind disorder of Clementine mandarin. However, spots have turned into yellow brownish to dark brown, dry areas in Clementine mandarin and thus considering the similar symptoms the disorder could be identified as rind disorder in lemon. Further, in puffing disorder in *C. limon*, rind was separated from the flesh and slight depressions on the fruit peel could be observed with an uneven appearance on the outer surface (Fig. 2-F).

Physiological disorders observed in Citrus crenatifolia

When considering the physiological disorders of *C. crenatifolia*, there were five disorders observed including chilling injury, oleocellosis, SERB, fruit cracking and rind disorder. In chilling injured fruits, small brown patches and water soaked lesions were observed with a discoloration on the flavedo once fruits were taken to warmer room temperature (Figure 3-A). Greenish yellow color areas and irregular sunken spots were observed on the flavedo in olecellosis disordered fruits (Fig. 3-B).

According to the observations of SERB in *C. crenatifolia*, fruit tissue has disintegrated near button end and a white color ring of necrotic tissue around the stem-end was clearly visible (Fig. 3-C). This result was slightly different from the previous observations reported by Ritenour et al. (2004) in SERB of Mandarin (*C. reticulata*). However, an unaffected tissue was observed near the button and darkening and collapse of the surface cells were observed around the stem-end in mandarin (Ritenour et al., 2004).

Fruit cracking disorder in *C. crenatifolia*, indicated a prominent crack originated from bottom of the fruit and the tissues adjacent to the cracked surface were severely damaged (Fig. 3-D). Results of the present study are in agreement with previous observations of fruit cracking in Navel orange reported by Li and Chen (2017). They have reported that the cracking has started from the central fruit axis and developed to the fruit top and finally a fracture has formed.

According to the observations made on rind disorder of *C. crenatifolia*, a hazy appearance on the entire fruit surface and irregular shaped, colorless small sized patches were visible on the flavedo. These observations were slightly different from the rind disorder in Nadorcott mandarin (*C. reticulata*) reported by Cronjé (2013). Dark pitting like symptoms and brown or reddish-brown discoloration were observed in a random pattern over the fruit surface in Nadorcott mandarin.

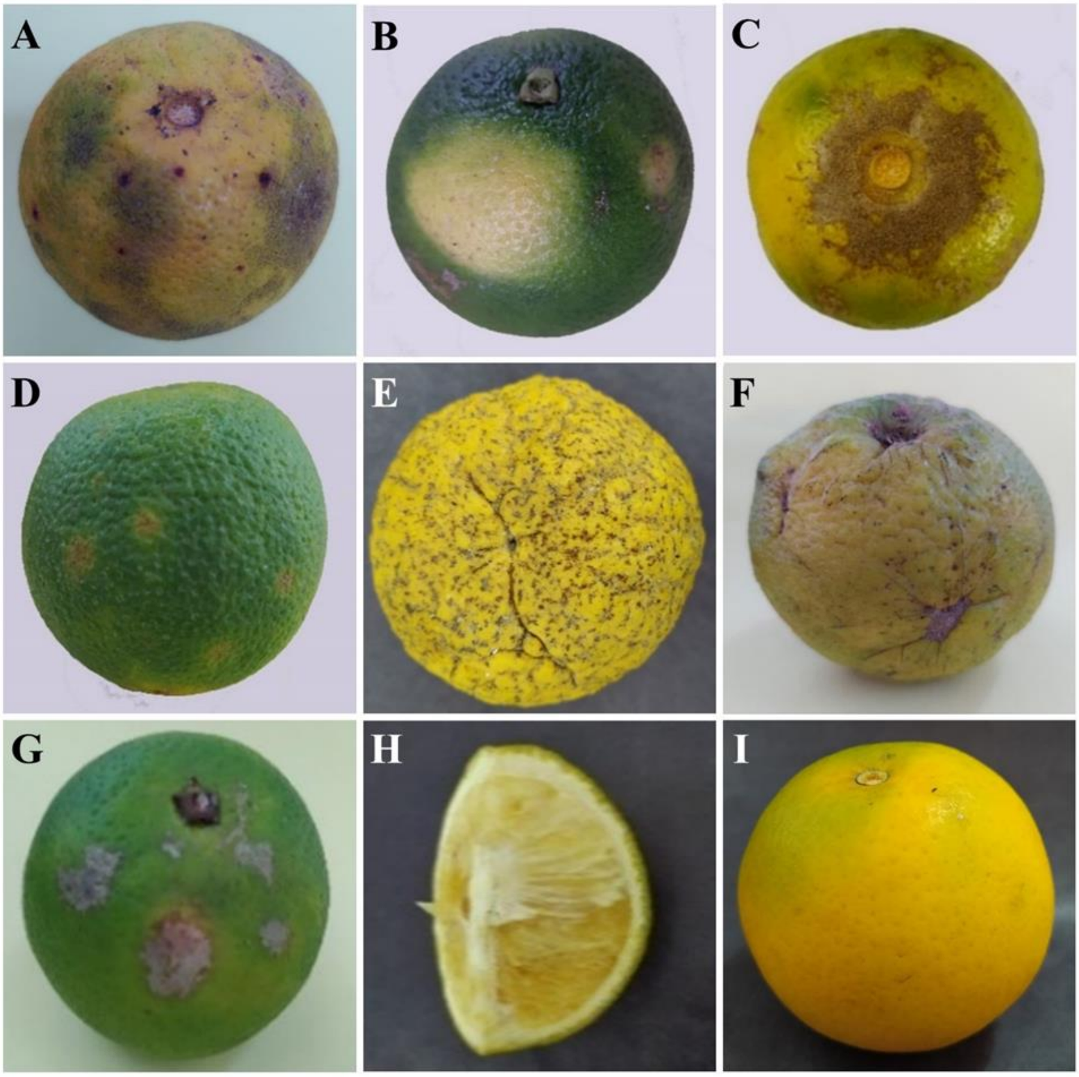

Fig. 1. Physiological disorders of *Citrus sinensis*: (A) Chilling injury, (B) Sun burn, (C) Stem-end rind breakdown, (D) Oleocellosis, (E) Peel pitting, (F) Puff and crease, (G) Wind injury, (H) Granulation, (I) Control.

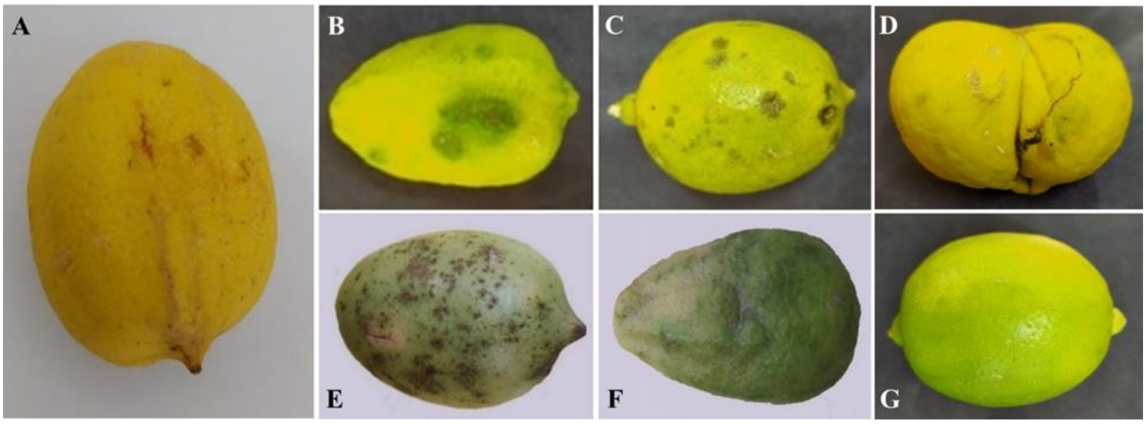

Fig. 2. Physiological disorders of *Citrus limon*: (A) Chilling injury, (B) Oleocellosis, (C) Peteca, (D) Fruit splitting, (E) Rind disorder, (F) Puffing, (G) Control.

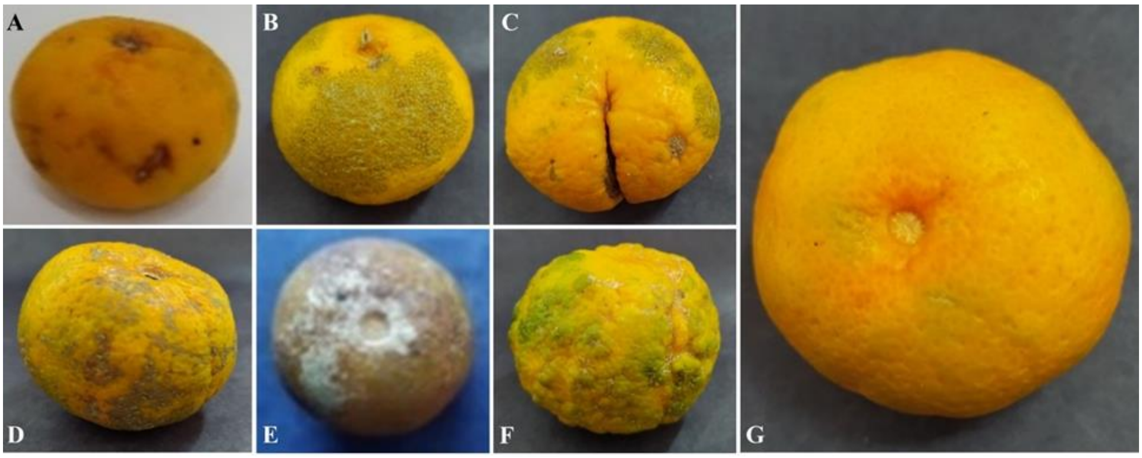

Fig. 3. Physiological disorders of *Citrus crenatifolia*; (A) Chilling injury, (B) Oleocellosis, (C) Fruit cracking, (D) Rind disorder, (E) Stem-end rind breakdown, (F) Puffing, (G) Control.

When considering the causes of physiological disorders in *Citrus* fruits, most of them are due to environmental factors. As stated by Kader (2002), chilling injury occurs mainly when fruits are kept at low temperatures below 10-15 °C for a certain period and when fruits were taken back into warmer temperatures. Oleocellosis results from the phytotoxic effect of the oil released from oil cavities surrounding the pericarp of *Citrus* fruits. Furthermore, oleocellosis results from several types of injuries including insect attack, via contact of damaged fruit with undamaged fruit or wind rub (Montero et al., 2012). Several recent findings have reported that, SERB is associated with drying conditions arising from factors such as holding the fruit under high temperatures and low humidity (Maria & Lorenzo, 2006; Ritenour & Dou, 1969). Dreistadt, 2012, has reported that, wind injury occurs in areas with persistent winds. Due to the wind, fruits on the outer canopy will be scarred where twigs or thorns rub against the rind. Sun burn was observed to be caused by heat produced due to the direct exposure to intense sunlight and this disorder could be observed normally where light intensity is very high (Dreistadt, 2012). These findings revealed that physiological disorders of *Citrus* fruits occur due to the failure of some physiological processes of the fruit tissues and as a result of biotic and abiotic stresses. Temperature, light, aeration, relative humidity, moisture are the abiotic factors that could contribute to physiological disorders in fruits. Further, pathogens, pests, insects are considered as biotic factors that cause these disorders (Ladaniya, 2008).

Evaluation of sensory properties

Fresh *Citrus* fruits should have prerequisite internal and external quality when it reaches the consumer. The fruit quality can be defined as the combination of fruit characteristics that have significance in determining the degree of consumer acceptance. Consumers evaluate fruit quality using their own senses at the time of purchase. Thus, sensory evaluation is equally important for deciding the marketability of fruit and the fruit quality can also be evaluated by the physicochemical properties (Cano-Lamadrid et al., 2018; Ladaniya, 2008). The sensory evaluation is subjective and it depends on the response of human senses to external and internal fruit quality. For example, the external quality parameters (peel color and texture) are mostly related to the senses of vision, touch and the internal quality of fruit is governed by taste, flavor and aroma of juice or flesh (Ladaniya, 2008).

Table 1. Sensory properties of *Citrus sinensis* with different physiological disorders

Physiological Disorder	Peel colour	Aroma	Texture	Taste	Flavour	Overall acceptability
Chilling injury	4.70^{b} ± 0.39	7.20^{a} ± 0.62	5.70^{b} ± 0.47	6.90^{a} ± 0.58	6.40^{a} ± 0.81	6.80^{a} ± 0.49
Oleocellosis	6.10^{b} ± 0.70	6.40^{b} ± 0.30	6.70^{a} ± 0.47	6.70^{a} ± 0.44	6.50^{a} ± 0.47	7.10^{a} ± 0.37
Puff & crease	4.70^{b} ± 0.21	5.20^{b} ± 0.57	3.70^{b} ± 0.57	6.90^{a} ± 0.52	6.50^{a} ± 0.54	6.00^{a} ± 0.55
Sunburn	7.00^{a} ± 0.36	7.30^{a} ± 0.36	5.90^{b} ± 0.34	6.10^{a} ± 0.54	6.00^{a} ± 0.55	5.90^{a} ± 0.34
Control	9.70^{a} ± 0.15	7.80^{a} ± 0.49	8.10^{a} ± 0.23	7.50^{a} ± 0.47	7.50^{a} ± 0.47	7.30^{a} ± 0.36

Each value represents the mean of ten replicates ± standard error. Means sharing a common letter(s) within the same column are not significantly different by Kruskal Wallis non-parametric test.

Table 2. Sensory properties of *Citrus limon* with different physiological disorders

Physiological disorder	Peel colour	Aroma	Texture	Taste	Flavour	Overall acceptability
Chilling injury	6.30^{a} ± 0.53	6.60^{a} ± 0.47	6.30^{a} ± 0.53	5.20^{a} ± 0.35	4.80^{a} ± 0.49	5.50^{a} ± 0.67
Rind disorder	5.10^{b} ± 0.67	5.60^{b} ± 0.34	6.10^{b} ± 0.56	4.70^{a} ± 0.53	4.30^{a} ± 0.44	4.40^{b} ± 0.49
Puff & crease	3.20^{b} ± 0.46	4.20^{b} ± 0.51	4.40^{b} ± 0.76	4.50^{a} ± 0.34	3.90^{a} ± 0.34	4.00^{b} ± 0.39
Peteca	5.20^{b} ± 0.66	6.00^{a} ± 0.29	5.90^{b} ± 0.34	5.10^{a} ± 0.34	5.30^{a} ± 0.39	5.60^{a} ± 0.42
Control	9.20^{a} ± 0.24	8.00^{a} ± 0.29	7.60^{a} ± 0.42	6.10^{a} ± 0.27	5.60^{a} ± 0.58	6.90^{a} ± 0.37

Each value represents the mean of ten replicates ± standard error. Means sharing a common letter(s) within the same column are not significantly different by Kruskal Wallis non-parametric test.

Table 3. Sensory properties of *Citrus crenatifolia* with different physiological disorders

Physiological Disorder	Peel colour	Aroma	Texture	Taste	Flavour	Overall acceptability
Chilling injury	3.30^{b} ±0.47	5.00^{a} ±0.63	3.60^{b} ±0.61	4.90^{b} ±0.48	5.00^{a} ± 0.33	5.30^{a} ±0.39
Oleocellosis	3.80^{b} ± 0.74	4.80^{b} ± 0.29	4.80^{a} ±0.44	4.20^{b} ±0.44	4.00^{b} ±0.47	5.00^{b} ±0.39
Rind disorder	3.40^{b} ± 0.68	5.20^{a} ± 0.46	4.20^{b} ±0.61	4.70^{b} ±0.61	4.50^{b} ± 0.50	4.70^{b} ±0.47
Puff & crease	2.50^{b} ± 0.34	4.90^{b} ±0.52	2.80^{b} ±0.24	4.90^{b} ±0.54	4.60^{b} ±0.58	4.30^{b} ±0.57
Fruit cracking	3.30^{b} ± 0.42	3.80^{b} ±0.53	5.00^{a} ±0.55	4.50^{b} ±0.45	4.40^{b} ±0.52	4.10^{b} ±0.58
Control	9.00^{a} ± 0.44	7.70^{a} ±0.55	7.80^{a} ±0.41	7.30^{a} ±0.53	6.60^{a} ± 0.47	7.20^{a} ±0.38

Each value represents the mean of ten replicates ± standard error. Means sharing a common letter(s) within the same column are not significantly different by Kruskal Wallis non-parametric test.

Sensory properties of *C. sinensis* (Green cultivar) fruits that displayed different physiological disorders were not significantly different from the control with respect to taste, flavor and overall acceptability. These results indicate that the taste and flavor has not been significantly affected by the physiological disorders of *C. sinensis* fruits. However, peel color, aroma and texture of the physiologically disordered fruits were significantly different from the control. Scores obtained for peel color of the fruits which have chilling injury (i.e. 4.70) and puff and crease (i.e. 4.70) were significantly different from that of the control (i.e. 9.70). Furthermore, texture of the fruits with puff and crease disorder obtained the minimum score (i.e. 3.70) (Table 1).

Sensory properties of *C. limon* fruits subjected to several physiological disorders were not significantly different from the control with respect to taste and flavor. However, peel color, aroma, texture and overall acceptability of the physiologically disordered fruits were significantly different from the control. All the sensory properties of the fruits with puff and crease disorder had the minimum scores. However, scores obtained for taste and flavor were not significantly different from the control and these properties were within the ranges of 4.50 – 6.10 and 3.90 – 5.60 respectively which scored lower values. Therefore, sensory evaluation reveals that the taste and flavor have not been significantly affected by the physiological disorders of *C. limon* fruits (Table 2).

Sensory properties of *C. crenatifolia* fruits showing physiological disorders were significantly different from the control. Scores obtained for peel color ranged between 2.50 – 9.00 in physiologically disordered fruits and the fruits with puff and crease disorder had the least score for peel color. Moreover, texture was also less (i.e. 2.80) in puff and crease disordered fruits when compared to the control fruits (i.e. 7.80). Further, flavor and taste were also significantly different in the physiologically disordered fruits when compared to the control fruits (Table 3).

These findings revealed that the taste and the flavor have not significantly been affected by the physiological disorders in *C. sinensis* and *C. limon* species. However, peel color, texture and aroma have been affected by physiological disorders in both fruit species. In addition to that, all the sensory properties were significantly different in *C. crenatifolia* fruits when compared to the control. Therefore, majority of the physiological disorders may affect the peel, but do not affect the edible internal portion of the *Citrus* fruits.

Assessment of physicochemical properties

Physicochemical properties are chemical qualities which provide fairly good information about nutritive value and fresh fruit quality. pH is a very important measure of fruit palatability which depends on the total amount of acids (Siriwardhana et al., 2017). TSS of fruits is a useful indication of soluble carbohydrates, organic acids, proteins and minerals present in a fruit. TSS represents about 10-20% of the fruit's fresh weight and it increases as fruit matures to produce a less acidic, sweeter fruit (Rodrigo, 2012). Further, firmness is considered as a useful measurement for determination of the ripeness and palatability of fruits (Siriwardhana et al., 2017). Ascorbic acid content is very important as it represents the vitamin C amount present in fruits and it is a water-soluble essential nutrient which also acts as an antioxidant (Herath et al., 2016; Turner & Burri, 2013).

As shown in Figure 4, pH of *C. sinensis* fruits ranged from 2.73 to 3.81, TSS from 7.36 to 9.00 ^{0}Brix and firmness between 2.90 - 4.80 kg cm^{-2} in all fruit samples. However, pH of *C. sinensis* fruits which were subjected to oleocellosis and sun burn were significantly different compared to the control. Further, TSS of peel pitting disordered fruits was significantly different in comparison to the control. Moreover, firmness of fruits which were subjected to sunburn was significantly lower compared to oleocellosis and peel pitting disordered fruits and the control. Ascorbic acid concentration ranged between 38.06 – 42.70 mg/100 mL. Oleocellosis and peel pitting indicating fruits displayed higher values and sun burnt fruits showed lower values for ascorbic acid content when compared to the control. According to Shravan et al. (2018), pH, TSS and ascorbic acid content of *C. sinensis* fruits were 3.8, 11 °Brix and 46.5 mg/100 mL) respectively. According to the results reported by Al-Mouei (2014), pH of different *C. sinensis* varieties ranged between 2.73 – 3.80, while TSS and ascorbic acid concentration have varied between 8.7 – 11.7 °Brix and 35.59 – 45.73 mg/100 mL) respectively. Notably, physicochemical parameters of control and physiologically discorded *C. sinensis* fruits determined in the present study were within range of the results reported by Shravan et al. (2018) and Al-Mouei (2014). Therefore, it can be inferred that physiochemical properties of *C. sinensis* fruits have not been adversely affected by different physiological disorders.

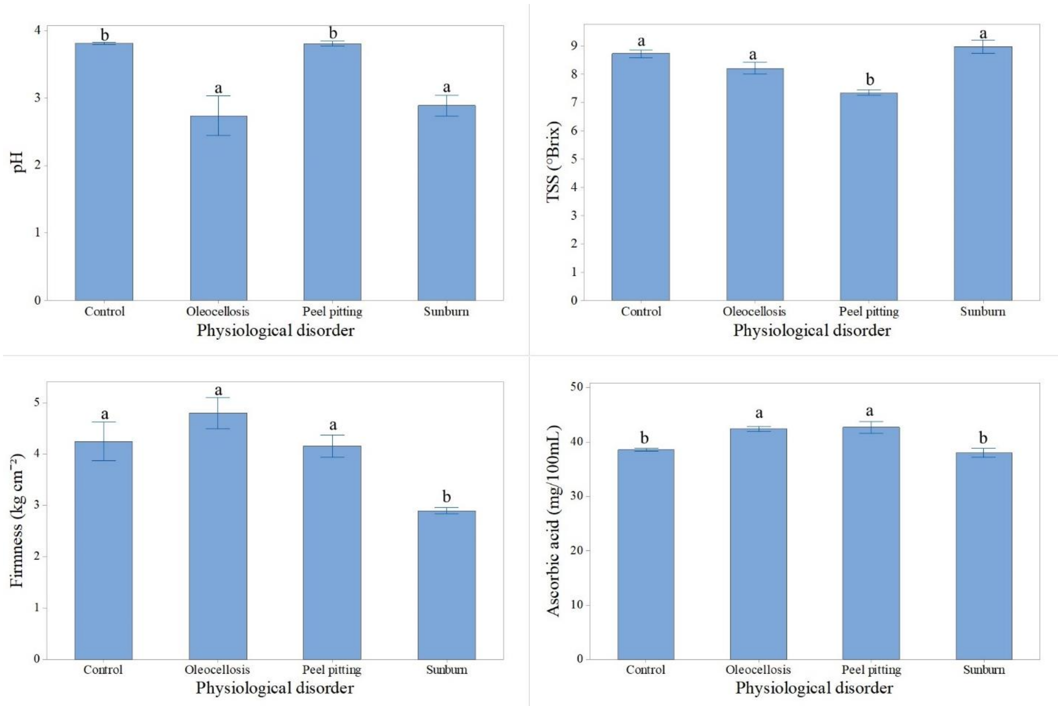

Fig. 4. Physicochemical properties of *Citrus sinensis* fruits with different physiological disorders. Each data point represents the mean of three replicates ± standard error. Means sharing a common letter(s) in each panel are not significantly different by Tukey's multiple comparison tests.

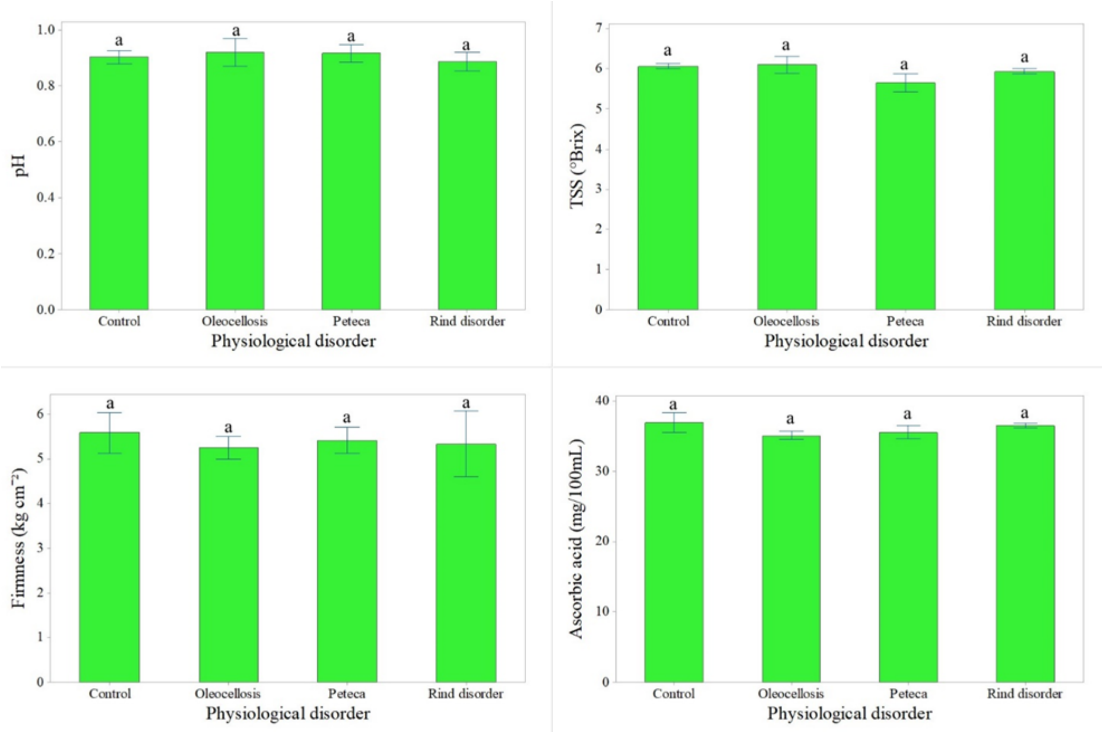

Fig. 5. Physicochemical properties of *Citrus limon* fruits with different physiological disorders. Each data point represents the mean of three replicates ± standard error. Means sharing a common letter(s) in each panel are not significantly different by Tukey's multiple comparison tests.

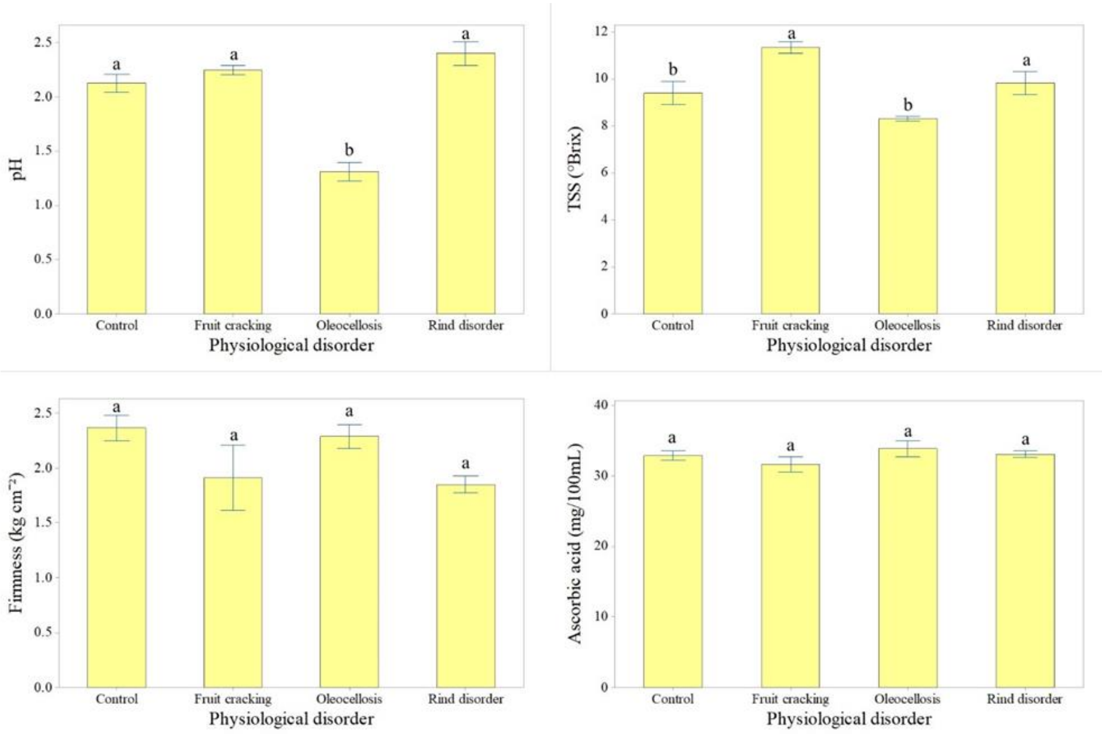

Fig. 6. Physicochemical properties of *Citrus crenatifolia* fruits with different physiological disorders. Each data point represents the mean of three replicates ± standard error. Means sharing a common letter(s) in each panel are not significantly different by Tukey's multiple comparison tests.

In *C. limon* fruits, pH, TSS, firmness and ascorbic acid concentration were not significantly different when compared to the control (Fig. 5). Therefore, it can be inferred that the physicochemical properties of *C. limon* fruits have not been affect by physiological disorders such as oleocellosis, rind disorder and peteca. pH ranged between 0.88-0.92 in all samples of *C. limon* fruits. TSS varied between 5.65 – 6.10 ^{0}Brix while firmness was observed between 5.25 – 5.58 kg cm^{-2} for all samples. Further, ascorbic acid concentration was within the range of 35.06 – 36.46 mg/100 mL for all samples tested. According to Al-Mouei (2014), pH, TSS and ascorbic acid concentration of *C. limon* fruits were reported at 2.21 – 2.46, 6.1 – 7.9 ^{0}Brix and 22.52 – 31.11 mg/100 mL respectively. Therefore, most of the physicochemical parameters of *C. limon* determined during the present study are in agreement with Al-Mouei (2014), except pH.

As shown in Figure 6, pH of oleocellosis indicating *C. crenatifolia* fruits and TSS of rind disorder and fruit cracking indicating fruits were significantly different when compared to the control. pH ranged from 1.31 to 2.40, while TSS varied between 8.30 – 10.33 ^{0}Brix in all samples tested. Firmness was within the range of 1.85 – 2.36 kg cm^{-2} and ascorbic acid concentration was between 31.63 - 33.90 mg/100 mL However, firmness and ascorbic acid content was not significantly different when compared to the control. Therefore, firmness and ascorbic acid concentration of *C. crenatifolia* fruits may not be altered by physiological disorders.

CONCLUSION

Many physiological disorders were recorded from selected *Citrus* fruit species (*C. sinensis, C. limon* and *C. crenatifolia*) including chilling injury, sun burn, SERB, oleocellosis, rind disorder, puff and crease, granulation, wind injury, peteca, fruit splitting and fruit cracking. Most of the disorders were observed in peels of *Citrus* fruits. According to the overall result of sensory analysis, majority of the physiological disorders affect the peel (peel color and texture) but does not the edible internal portion (taste and flavor) of the *Citrus* fruits. However, postharvest fruit market value is decreased since external appearance is the primary requirement used to evaluate fruit quality. Furthermore, physicochemical properties of *C. limon* were not affected by physiological disorders whereas physicochemical properties of *C. sinensis* and *C. crenatifolia* have been affected by physiological disorders. This is the first report on characteristics of physiological disorders of green cultivar of *C. sinensis* and *C. crenatifolia*. Identification of physiological disorder symptoms along with physicochemical and sensory properties will be valuable for horticulture industry to lessen post-harvest quality loss and to develop management strategies.

Conflict of interest

The authors declare no conflict of interest to report.

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