Emirates Journal of Food and Agriculture. 2022. 34(12): 1072-1078
doi: 10.9755/ejfa.2022.v34.i12.2980
http://www.ejfa.me/

REGULAR ARTICLE

The fruit peel anatomy, leaf nutrient content, and fruit quality of 'Terigas' mandarin in relation to fruit cracking

Hardiyanto*, N. F. Devy, M. E. Dwiastuti, A. Sugiyatno, H. Ashari, O. Endarto, A. Triwiratno, C. Martasari[1]

National Research and Innovation Agency, Cibinong Science Center Jalan Raya Bogor KM. 46, Cibinong, West Java, Indonesia

ABSTRACT

'Terigas' mandarin is one of the cultivars cultivated in almost all of Indonesia's provinces. However, this cultivar is prone to cracking, and little research has been conducted on fruit cracking in Indonesia. The goal of this study was to determine the effect of fruit cracking on peel anatomy, leaf nutrient content, and fruit quality in 'Terigas' cultivar. A Completely Block Design (CBD) with three replications was used. Results showed that the peel thickness of uncracked with big fruit size was significantly the highest, while epidermis of cracked fruit with big size was the thickest. The largest oil glands size was shown in uncracked fruit with a big size. The leaf that supported uncracked fruit with a big size had the highest Ca content, whereas the lowest Ca content was observed in the leaf that supported cracked fruit with a small size. In contrast, the leaf that supported cracked with a small fruit size had the highest Zn content. Regardless of fruit size, fruit weight, fruit diameter, and pH of uncracked fruit were significantly much higher than cracked ones. Nevertheless, the Total Soluble Acid and vitamin C of cracked fruit were significantly higher than uncracked ones. This study may provide the important keys to the fruit cracking effect, and as a tool to lessen citrus fruit cracking, especially in 'Terigas' mandarin.

Keywords: Citrus; Cracking; Mandarin; Terigas; Zn.

INTRODUCTION

The physiological disorder is one of the serious problems encountered in some fruit crops, resulting in a loss of quality and economic production (Xylia et al., 2021). It affected more than 60% of global citrus production, with the most common symptom being physical damage to the fruit such as cracking and splitting in several citrus productions (Agustí et al., 2001; Chabbal et al., 2020). Fruit cracking can result in yield losses of up to 65% in pomegranate (Singh et al., 2020), and up to 75% in cherry (Solanki et al. 2019). In citrus, fruit cracking could occur via inner-cracking, flavedo-splitting, and albedo-splitting. These types were dependent on species, varieties, and stage of fruit development (Li & Chen., 2017). It is also reported that 90% of citrus cracking was due to radial cracking, whereas only 10% showed transversal cracked (Elavarasan & Premalatha, 2019). Moreover, Stander et al. (2014) confirmed that fruit cracking of mandarin varieties began from the base of naval or stylar end and progressed up to endocarp. Regarding species or varieties effect, splitting or cracking traits was embedded in some citrus cultivars like 'Nova' mandarin (García et al., 2001; Cronjé et al., 2013; Jayasekara et al., 2021). The fruit shape of the split character was more oblate with a bigger navel size as compared to the non-split. Likewise, the pulp and rind also affect cracked fruit in several citrus species and varieties as well. The development of pulp during fruit growth tends to micro-crack development before macro-crack formation in the exocarp (Wang et al., 2021). Reports by Khadivi-Khub (2015) and Demirsoy & Demirsoy (2004) mentioned that fruit cracking was correlated to some fruit traits. The occurrence of fruit cracking might be due to the unorganized rapid absorption of water through the vascular system that influences the unequal increase in fruit turgor pressure (Balbontín et al., 2013; Galindo et al., 2014; Kaur et al., 2019).

It was also reported that plant nutrient contents and concentrations as well triggered cracked fruit in mandarin cv. Nova (Odemis et al., 2014). About the nutrient effect on fruit cracking, it seems that an increasing concentration

***Corresponding author:**
Hardiyanto, National Research and Innovation Agency, Cibinong Science Center Jalan Raya Bogor KM. 46, Cibinong, West Java, Indonesia.
E-mail: hardiyanto85@yahoo.com

Received: 21 February 2022; **Accepted:** 04 December 2022

of N leads to fruit cracking. It means that N content in the fruit peel is significantly affected by N content in the leaf (Ahmed et al., 2021; Khalil et al., 2022). Based on the study in pomegranate, indicated that N and K/Ca content in the leaf were correlated with the leaf texture attribute such as succulence that enhances splitting or cracking (Hepaksoy et al., 2000; Ahmed et al., 2022). In addition, leaf succulence was also due to increased Ca content and decreased K content in the leaf.

'Terigas' cultivar belongs to mandarin group that is commercially grown both in low and high land areas in almost all regions in Indonesia. However, based on DNA markers, it was classified into one cluster with tangerine that had a genetic similarity up to 85% (Hardiyanto et al. 2021). Terigas is prone to cracking, as a result, it is an intriguing topic to investigate to determine the cracking phenomenon, particularly in relation to anatomy attributes, leaf nutrient content, and fruit quality. Therefore, this study objectives are to determine the effect of fruit cracking on peel anatomy, leaf nutrient content, and fruit quality in 'Terigas' cultivar.

MATERIALS AND METHODS

Research site and plant materials

This study was carried out at Indonesian Citrus and Subtropical Fruit Research Institute (ICISFRI) from June to November 2021. Eight-year-old of 'Terigas' mandarin tree which had both cracked and uncracked fruits was used. Cracked with a skin break of ≥ 1.0 cm long and uncracked fruits of different sizes were selected for observation. (Table 1; Fig. 1).

Fruit peel anatomy, peel and epidermis thickness, and oil glands size

Observation of fruit peel anatomy derived from cracked and uncracked fruit was done at MIPA laboratory, State University of Malang, East Java, Indonesia. The samples were coated with Aurum-Palladium (Au-Pd) before being examined under Scanning Electron Microscopy (merk FEI type inspect S50). The peel and epidermis thickness, as well as oil glands size were taken from the fruit of different sizes (n = 3) (Table 1). These samples were analyzed at the Faculty of Biology, Gajah Mada University, Center of Java, Indonesia. These variables were determined using the modified method of Agustí et al. (2001).

Leaf sampling and leaf nutrient content

Leaf sampling used for analyzing leaf nutrient content was classified into six categories (Table 2). The concentration of nutrient content was determined using modified method of Ayoub et al. (2014). Meanwhile, equipment used in this study were UV-Vis Spectrophotometer and Atomic Absorption Spectrophotometer (AAS).

Fruit quality

There were two measurements of fruit quality: 1) fruit quality derived from uncracked and cracked fruit, and 2) fruit quality derived from three types of trees (a tree with all uncracked fruit with the big size, a tree containing both uncracked fruits with the big size and cracked fruit with the medium size, and tree with both uncracked fruit with big size and cracked fruit with the small one). Fruit weight and fruit diameter were measured from the average of 5 fruits per treatment (uncracked and cracked fruit). Total Soluble Solid and pH were detected by hand refractometer and pH meter, respectively. Total Soluble Acid and Vitamin C were determined by the Titrimetric method (Sallato et al., 2017; Xylia et al., 2022).

Experimental design

Completely Block Design (CBD) was only used for analyzing peel and epidermis thickness, oil glands size, leaf nutrient content that consisted of 6 treatments with 3 replications, respectively, and fruit quality derived from three types of trees that it consisted of 3 treatments with 3 replications.

Table 1: Fruit size classification used as fruit sample

Code	Fruit size classification	Fruit diameter (cm)
UCB	Uncracking with big size	5.1 – 7.0
UCM	Uncracking with medium size	3.1 – 5.0
UCS	Uncracking with small size	1.0 – 3.0
CB	Cracking with big size	5.1 – 7.0
CM	Cracking with medium size	3.1 – 5.0
CS	Cracking with small size	1.0 – 3.0

Table 2: Leaf sampling categories for leaf nutrient analyses

Code	Categories
LUCB	Leaf supporting uncracked fruit with big size
LUCM	Leaf supporting uncracked fruit with medium size
LUCS	Leaf supporting uncracked fruit with small size
LCB	Leaf supporting cracked fruit with big size
LCM	Leaf supporting cracked fruit with medium size
LCS	Leaf supporting cracked fruit with small size

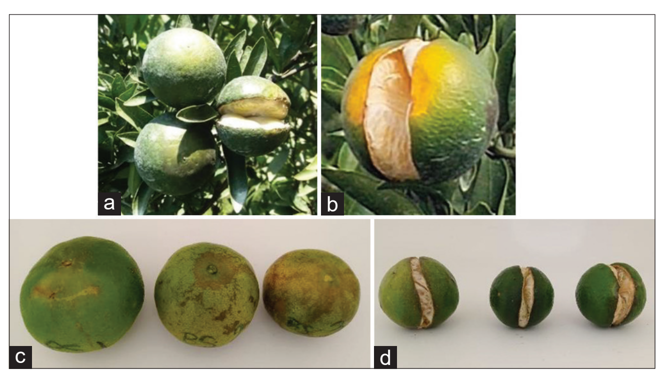

Fig 1. Selected cracked fruit from 'Terigas' tree to be observed (a, and b), and fruit size classification of uncracked fruit (c), and cracked fruit (d).

Statistical analyses

Statistical analyses of variance have been done for this experiment using MINITAB 16 statistical software. The data obtained were analyzed by Tukey's test ($P < 0.05$). Comparison between two mean values of peel and epidermis thickness, oil gland size, and fruit quality of uncracked and cracked fruit, respectively, were measured by paired *t*-test.

RESULTS AND DISCUSSION

Fruit peel structure, peel and epidermis thickness, and oil glands size

The fruit shape of 'Terigas' mandarin was oblate. Scanning electron micrograph detected difference surface of peel structure between uncracked and cracked fruit. In cracked fruit, peel structure was disorganized and little roughly as compared to uncracked fruits that more smooth and uniform (Fig. 2a,b). Almost all species of citrus have a rind that consists of flavedo and albedo. Nevertheless, the structure of flavedo or albedo varied among citrus cultivars. The initial symptoms of microcracks in the rind that due to the rapid pulp development during fruit growth took place in the areas of epicarp and mesocarp (Agustí et al., 2001; Juan et al., 2011; Cronjé et al., 2013). Furthermore, Yong et al. (2006) also stated that gene expression involved in the growth of pericarp or aril that was associated with fruit cracking in litchi cultivars. The accumulation of expansin gene named *LcExp1* was detected in both pericarp and aril of the cracking-susceptible cultivar (Nuomici), and the cracking-resistant cultivar (Huaizi). Nevertheless, the other expansin *LcExp2* was only observed in the pericarp of Huazi cultivar.

Differences of peel and epidermis thickness, and oil glands size as well derived from the cracked and uncracked fruit peel with different sizes were obtained. The average of peel and epidermis thickness with the highest values ($p \leq 0.05$) were uncracked (224.80±16.5 μm; R^2=97.80%) and cracked one (1.29±0.02 μm; R^2= 98.89%) with the big size, respectively. Nevertheless, the last value was not influenced by the size of its fruit. In this study, the highest oil gland size was observed in uncracked fruit with a big size (104.59±21.02 μm) (Table 3).

Based on the anatomy observation, peel thickness characters of uncracked and cracked fruit of terigas mandarin were observed (Fig. 3a,b), meanwhile, the oil glands of cracked fruit were malformed, whereas for healthy ones they were more well developed (Fig. 3c,d). Regardless of fruit size, the peel of uncracked fruit was significantly thicker ($p \leq 0.01$) than cracked one (Fig. 4a), whereas, the epidermis thickness of cracked (1.07±0.23 μm) and uncracked fruit (1.003±0.12 μm) were not significantly different (Fig. 4b). On the other hand, based on fruit size, epidermis thickness was significantly ($p \leq 0.05$) influenced by fruit size (Fig. 4c).

Hardiyanto & Devy (2019) mentioned that the crack of tangerine fruit was related to the thinnest of fruit peel. It seems that the healthy fruit has a thicker albedo than that of the cracked one, although the albedo attribute was not

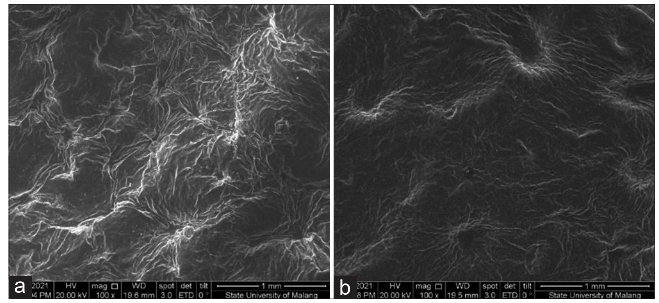

Fig 2. Scanning electron micrographs of surface peel of cracked fruit (a), and uncracked fruit (b); x 100

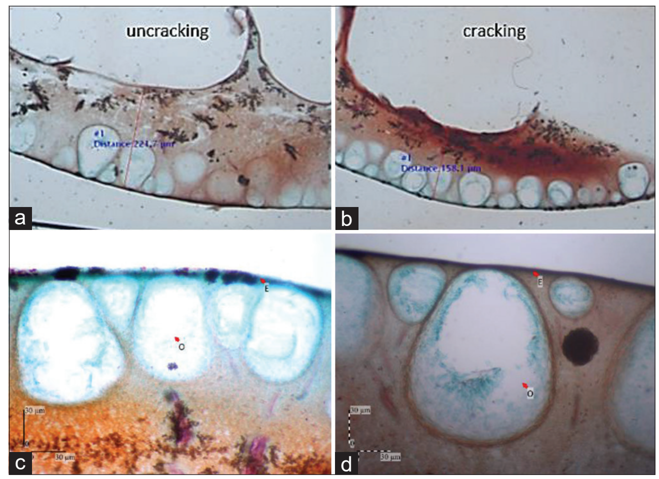

Fig 3. Peel thickness character of uncracking (a), and cracking b); and epidermis thickness and oil glands of cracked big fruit (c), uncracked big fruit (d). E= epidermis; O= oil glands. x 40.

Table 3: The average peel thickness, epidermis thickness, and oil gland size

of 'Terigas' Mandarin	Peel thickness (μm)	Epidermis thickness (μm)	Size of oil glands (μm)
UCB	224.80±16.50^{a}	0.99±0.02^{c}	104.59±21.02^{a}
UCM	131.30±12.10^{d}	1.14±0.03^{b}	58.51±10.24^{b}
UCS	187.80±10.00^{b}	0.87±0.02^{d}	50.29±3.93^{b}
CB	159.30±10.50^{c}	1.29±0.02^{a}	77.25±15.17^{ab}
CM	139.10±6.40^{d}	1.14±0.01^{b}	59.51±13.62^{b}
CS	169.10±17.70^{c}	0.78±0.02^{e}	53.79±7.27^{b}
		**	**
R^2 (%)	97.80	98.89	75.35

Total number of sample (n = 3)
Value with the different letters was significantly different according to Tukey's test at 0.05 level
UCB= uncracked with big size; UCM= uncracked with medium size; UCS= uncracked with small size; CB= cracking with big size; CM= cracking with medium size; CS= cracking with small size

observed. In addition, Ohta (2017) stated that the thickness of exocarp and mesocarp was negatively correlated with fruit cracking in tomatoes. This finding was also in line with previous research conducted by L. Demirsoy & Demirsoy (2004) in sweet cherry. In relation to oil gland size without considering the fruit size, based on T-test, it was recorded that uncracked fruit had a larger oil glands size (71.13±28.34 μm) than cracked one (63.51±14.46 μm). Moreover, based on fruit size without considering the cracking, the big fruit size produced the largest oil gland size (Fig. 5a,b).

This finding was supported by the previous study that type of cracking (Li and Chen, 2017), different in anatomical structure (Wang et al. 2021), skin composition, and mechanical properties (Yang et al., 2016) varied among species and varieties as well that may cause the difference of epidermis thickness and size of oil glands. Knight et al. (2001) also revealed that oil glands of Washington navel orange developed along with fruit maturity stage until fruit diameter reached 30 to 50 mm. Nevertheless, this finding was opposite to Kaur et al. (2019) who mentioned that cracked fruit peel of lemon produced larger oil glands size (813.33 mm^2) as compared to peel of uncracked fruit (684.03 mm^2).

Moreover, Fischer et al. (2021) mentioned that crop management, fruit development stage, and season may also affect the anatomy and the composition of citrus peel. It seems that the bigger size of oil glans tends to reduce the density of oil glands that may increase cracking resistance. The information of oil gland structure is very important specially to study the rind disorder in the citrus genus, species as well as varieties.

Leaf nutrient content

Ayoub et al. (2014) reported that the mineral content of plant organs like leaves is a very important tool to determine the status of nutrients. By knowing this status, it could predict the status of nutrients in the fruit that may affect fruit cracking. In this study, leaf nutrient content with various positions varied among the treatments (Table 4). The leaf that supported healthy big fruit had the highest (3.08%) Ca content, whereas the lowest one (1.93%) of Ca content was shown by leaf supported the cracked fruit with small size. It was about 60.20% of Ca was absorbed

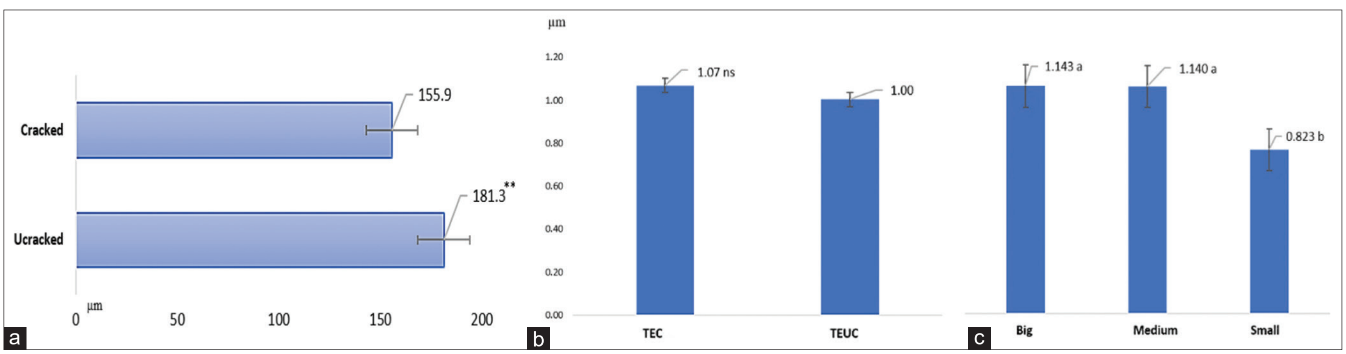

Fig 4. Peel thickness of cracked and uncracked fruit (a), epidermis thickness of cracked and uncracked fruit (b), and epidermis thickness of the big, medium, and small fruit (c). **statistically significantly different ($p < 0.01$) according to Student's *t*-test; *ns*: significantly different according to Student's *t*-test ($p < 0.05$); value with different letter was significantly different according to Tukey's test. TEC= thickness of epidermis from cracked; TEUC= thickness of epidermis from uncracked fruit.

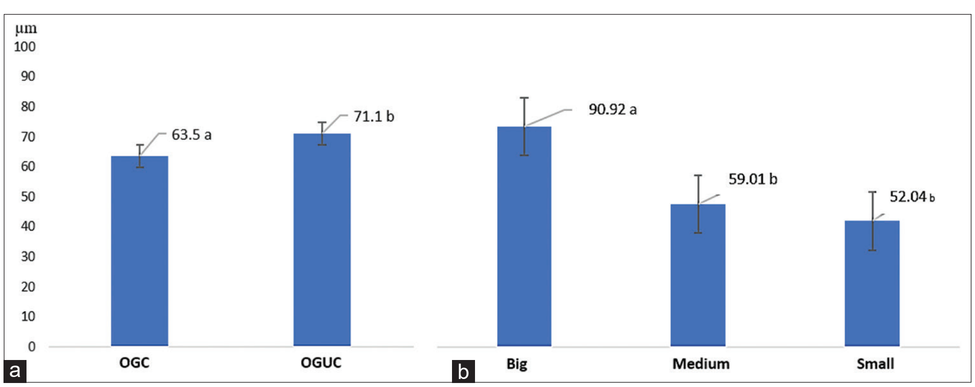

Fig 5. Oil gland size of cracked and uncracked fruit (a), and oil gland size of big, medium, and small fruit (b). Different letters indicate a statistically significant difference of OGC from the OGH using Student's t-test at level $p < 0.05$. Value with the different letters was significantly different according to Tukey's test at 0.05 level. OGC= Oil gland of cracked fruit; OGUC= Oil gland of uncracked fruit.

Table 4: The average of P, K, Ca, Zn, and B content in the leaf that supports healthy and cracked

fruit with different size	P (%)	K (%)	Ca (%)	Zn (ppm)	B (ppm)
LUCB	0.167±0.037	1.630±0.134	3.083±0.290[a]	105.747±13.519[ab]	65.097±7.419
LUCM	0.163±0.012	2.113±0.288	2.300±0.295[ab]	93.507±20.835[ab]	64.470±11.343
LUCS	0.180±0.037	1.973±0.410	2.323±0.441[ab]	74.050±12.012[ab]	68.567±4.302
LCB	0.167±0.009	1.497±0.207	2.480±0.220[ab]	72.550±20.970[ab]	72.307±16.548
LCM	0.160±0.008	1.563±0.175	2.257±0.355[ab]	53.360±11.395[b]	55.693±4.141
LCS	0.135±0.004	1.705±0.069	1.925±0.069 [b]	113.780±16.983[a]	66.180±3.821
	ns	ns	*	*	ns
R^2 (%)	26.34	46.15	57.43	61.67	23.21

Value with the different letters was significantly different according to Tukey's test at 0.05 level
LUCB: leaf supporting uncracked with big fruit; LUCM: leaf supporting uncracked with medium fruit; LUC: leaf supporting uncracked with small fruit; LCB: leaf supporting cracking with big fruit LCM: leaf supporting cracking with medium fruit; LCS: leaf supporting cracking with small fruit

by leaf supported uncracked with the big size as compared to leaf supported cracked with the small one.

Pham et al. (2012) concluded that lower levels of fruit- calcium (Ca) was correlated to albedo cracking. Increased Ca absorption in leaf and fruit would reduce albedo cracking in sweet orange cv. Washington Navel. Besides Ca, it seemed that the incidence of oranges-fruit cracking was also due to its size. It was detected that almost all fruit tissues of cracked fruits had Ca lower than healthy ones (Sallato et al., 2017). It is suggested that Ca involve in the cell membrane development, cell division of fruit. In the balance of Ca, content could induce physiological disorders like cracking.

Meanwhile, the Zn content of leaf-supported cracked fruit with small size was the highest (113.780 ppm). Huang et al. (2019) confirmed that leaf Zn content due to the foliar application would directly be transported to the fruit during fruit development. Applying this mineral to the leaves could increase its content at the Pecan embryos and would increase the quality of its fruits. The same result was also stated by Razzaq et al. (2013) in 'Kinnow' mandarin. In this research, we found that leaf content of P, K, and B were not significantly different among treatments, and it was supported by Morgan et al. (2005) who reported that there was no correlation between N or P concentrations in leaf or peel and the peel thickness. Hardiyanto & Devy (2019) also mentioned that nutrient levels in the leave was not correlated with a nutrient level in the fruit peel. Additionally, Hosseinifard & Panahi (2006) also confirmed that a negative correlation was shown between the percentage of K and Ca in the leaf of Pistachio.

Regardless of fruit size, the average leaf K content that supported uncracked fruit was much higher (1.91%) than the cracked one (1.59%) (Data was not shown). This result agreed with previously studied by Alva et al. (2006) who revealed that application of K applied would increase fruit quality in orange and grapefruit trees as well. The main role of K is to maintain cell osmotic potential and turgor pressure that tend to affect peel thickness and fruit diameter.

Fruit quality

The result showed that fruit weight, fruit diameter, and pH of uncracked fruit were significantly higher than that of cracked one. In contrast, total soluble acid (TSA), and Vit C of cracked fruit were significantly the highest, whereas total fruit segments, water content, and TSS gave the same response (Table 5). Fruit development of uncracked fruit was much better than that of cracked one that tends to trigger fruit weight and fruit diameter. The lower pH of cracked fruit in citrus was also reported by Winkler et al. (2015) and Lichter et al. (2002) in sweet cherry tomatoes. It seems that the activity of the cell walls and plasma membranes as well were involved, and low pH may also trigger the activity of polygalacturonase. About polygalacturonase activity, Habibi et al. (2021) confirmed that fruit splitting in oranges may be due to an increase in activity of polygalacturonase that causes a reduction in cell wall hardening and losing, peel thickness. The same finding was also shown by a previous study that TSA content of pomegranate and wax apple obtained from cracked fruit were higher than uncracked fruit (Zaouay et al., 2020**;** Lu & Lin, 2012), whereas, TSS content was not different between cracked and uncracked fruit of orange (Sallato et al., 2017). In contrast**,** Zhang and Mingzhu (2006) confirmed that higher TSS content of cracked fruit in *Prunus salicina* L. was detected as compared to healthy fruit.

Fruit quality derived from three types of trees was also observed. TSA content taken from trees with all uncracked fruit with the big size was higher (13.87±0.50%) than fruit taken from a tree containing both uncracked fruits with the big size and cracked fruit with the medium size (10.87±0.09%), and trees with both uncracked fruit with big size and cracked fruit with the small one (9.33±0.68%), meanwhile, TSS and vit C of fruit taken from 3 types of trees gave the same response (Data not shown). El-Sayed (2016) stated that the fruit position on both sides of the tree canopy and parts of the tree,

Table 5: Fruit weight, fruit diameter, total fruit segment, water content, pH, TSS, TSA, and Vit C derived from uncracked and cracked fruit

Treatment	Fruit weight (g)	Fruit diameter (mm)	Total fruit segment	Water content (cc)
Uncracked Fruit	118.20±13.0[a]	61.4±3.00[a]	10.3±0.67	87.5±2.50
Cracked Fruit	31.00 ±2.80[b]	40.8±1.60[b]	10.7±0.33	89.5±0.57
T-test (0.05%)	**	**	ns	ns
	pH	**TSS (⁰Brix)**	**TSA (%)**	**Vit C (mg/100 g)**
Uncracked Fruit	3.44±0.05[a]	8.98±1.20	22.85±0.07[b]	16.23±0.84[b]
Cracked Fruit	2.25±0.05[b]	8.51±0.08	23.29±0.03[a]	78.75±0.88[a]
T-test (0.05%)	**	ns	**	**

value with the different letters was significantly different according to Student's *t*-test.

and season also affected fruit splitting or cracking in Washington navel orange that could reduce fruit quality. In addition, Abd El-Rhman (2010) stated that the splitting tendency was related to the stage of fruit development in Washington navel orange.

CONCLUSIONS

Peel and oil glands of uncracked 'Terigas, mandarin fruit with big size were significantly the thickest and the largest, respectively, whereas, the epidermis thickness of peel derived from cracked one with big size was the thickest. Among leaf nutrient content, Leaf that supported uncracked fruit with big size had the highest Ca content, whereas, for leaf Zn content, a leaf that supported cracked fruit with small size produced the highest Zn content. Regardless of fruit size, leaf K content that supported uncracked fruit was higher than cracked fruit. Fruit weight and diameter, and pH of uncracked fruit were significantly higher than cracked fruit, whereas, total soluble acid and Vit C were significantly higher in the cracked fruit than uncracked one. TSA content taken from a tree with all uncracked fruit with the big size was higher than the other two types of trees. This finding will be valuable as a basis of further research about modifying nutrient recommendation and crop management, also as a tool to lessen fruit quality loss due to fruit cracking in "Terigas" mandarin in Indonesia.

Authors' contribution

Hardiyanto and N.F. Devy: concepted, set up the idea, designed, coordinated the experiment, carried out the experiment, observation, drafted the manuscript, corrected, and approved the final manuscript to be published. M.E. Dwiastuti and A. Sigiyatno: carried out the experiment, collected data, observation, drafted, reviewed, and corrected the manuscript. H. Ashari, O. Endarto, A.Triwiratno, and C. Martasari: performed the experiments, collected data, documentation, prepared samples to be analyzed, observation, statistical analysis, discussed the results, drafted, and corrected the manuscript.

REFERENCES

Abd El-Rhman, I. E. 2010. Physiological studies on cracking phenomena of pomegranates. J. Appl. Sci. Res. 6: 696-703.

Agustí, M., V. Almela, M. Juan, F. Alferez, F. R. Tadeo and L. Zacarías. 2001. Histological and physiological characterization of rind breakdown of 'Navelate' sweet orange. Ann. Bot. 88: 415-422.

Ahmed, Z. F. R., A. K. H. Alnuaimi, A. Askri and N. Tzortzakis. 2021. Evaluation of Lettuce (*Lactuca sativa* L .) Production under hydroponic system : Nutrient solution derived from fish waste vs. Inorganic nutrient solution. Horticulturae. 7: 292.

Ahmed, Z. F. R., N. Kaur and F. E. Hassan. 2022. Ornamental date palm and sidr trees : Fruit elements composition and concerns regarding consumption. Int. J. Fruit Sci. 22: 17-34.

Alva, A. K., D. Mattos Jr., S. Paramasivam, B. Patil, H. Dou and K. S. Sajwan. 2006. Potassium management for optimizing *Citrus* production and quality. Int. J. Fruit Sci. 6: 3-43.

Ayoub, M, R. Salghi, A. Abouatallah and S. M. Alaoui. 2014. Seasonal dynamic of mineral macronutrients in three varieties of clementine (*Citrus reticulate*) Leaves. Int. J. Eng. Res. Appl. 4: 195-200.

Balbontín, C., H. Ayala, R. M. Bastías, G. Tapia, M. Ellena, C. Torres, J. A. Yuri, J. Quero-García, J. C. Ríos and H. Silva. 2013. Cracking in sweet cherries: A comprehensive review from a physiological, molecular, and genomic perspective. Chil. J. Agric. Res. 73: 66-72.

Chabbal, M. D., M. D. L. M. Yfran-Elvira, L. I. Giménez, G. C. Martínez, L. A. Llarens-Beyer and V. A. Rodríguez. 2020. Control of fruit cracking in clementino mandarin plants. Cultiv. Trop. 41:e06.

Cronjé, P.J.R., O. P. J. Stander and K. I. Theron. 2013. Fruit splitting in citrus. Hortic. Rev. 41: 177-200.

Demirsoy, H and L. Demirsoy. 2004. A study on the relationships between some fruit characteristics in cherries. Fruits. 59: 219-223.

Demirsoy, L and H. Demirsoy. 2004. The epidermal characteristics of fruit skin of some sweet cherry cultivars in relation to fruit cracking. Pak. J. Bot. 36: 725-731.

El-Sayed, S. A. 2016. Some factors affecting orange fruit splitting of Washington Navel orange under kafr elsheikh conditions. A-the effect of rootstock. J. Plant Prod.7: 343-349.

Elavarasan, M and A. Premalatha. 2019. A review : Nutrient deficiencies and physiological disorders of citrus. J. Pharmacogn. Phytochem. 8: 1705-1708.

Fischer, G., H. E. Balaguera-Lopez and J. Álvarez-Herrerra. 2021. Causes of fruit cracking in the era of climate changes. Agron. Colomb. 39: 209-221.

Galindo, A., P. Rodríguez, J. Collado-González, Z. N. Cruz, E. Torrecillas, S. Ondoño, M. Corell, A. Moriana and A. Torrecillas.

2014. Rainfall intensifies fruit peel cracking in water stressed pomegranate trees. Agric. For. Meteorol. 194: 29-35.

García-Luis, A., A. M. M. Duarte, M. Kanduser and J. L. Guardiola. 2001. The anatomy of the fruit in relation to the propensity of *Citrus* species to split. Sci. Hortic. 87: 33-52.

Habibi, S., A. Ebadi, A. R. Ladanmoghadam and S. Rayatpanah. 2021. Effect of plant growth regulators on fruit splinting in Thompson Navel orange. Acta Sci. Pol. Hortorum Cultus. 20: 83-92.

Hardiyanto., N. F. Devy, S. Susanto, A. Sugiyatno, M. E. Dwiastuti and S. Widyaningsih. 2021. Morphological, physiological, pests and diseases responses of citrus seedling cultivars, and their contribution to cultivar classification under nursery house and open field. Emir. J. Food Agric. 33: 370-378.

Hardiyanto and N.F. Devy. 2019. Application of K, Ca, and Mg on peel thickness, and fruit cracking incidence of citrus. Russ. J. Agric. Socioecon. Sci. 87: 45-56.

Hepaksoy, S., U. Aksoy, H.Z. Can and M.A. Ui. 2000. Determination of relationship between fruit cracking and some physiological responses, leaf characteristics and nutritional status of some pomegranate varieties. Options Mediterr. 92: 87-92.

Hosseinifard, J and B. Panahi. 2006. The effect of different mineral nutrients on early splitting in pistachio. Acta Hortic. 726: 325-328.

Huang, R., C. Shen, S. Wang and Z. Wang. 2019. Zinc content and fruit quality of pecan as affected by application of zinc sulfate. HortScience. 54: 1243-1248.

Jayasekara, A., K. Abeywickrama, A. Daranagama and T. Kodituwakku. 2021. Physiological disorders of selected citrus fruit species in Sri Lanka and their effect on fruit quality. J. Hortic. Postharvest Res. 4: 385-398.

Juan, L. I., C. Jiezhong, W. Jifeng, H. Yongjing and Y. Qing. 2011. The correlation of cracking fruits types and peel structure between ‘ Washington ’ and ‘ Bonanza ’ Navel oranges. Chin. J. Trop. Crop. 32: 921-925.

Kaur, R., N. Kaur and H. Singh. 2019. Pericarp and pedicel anatomy in relation to fruit cracking in lemon (*Citrus limon* L burm.). Sci. Hortic. 246: 462-468.

Khadivi-Khub, A. 2015. Physiological and genetic factors influencing fruit cracking. Acta Physiol. Plant. 37: 1718.

Khalil, H. A and D. O. El-ansary, Z. F. R. Ahmed. 2022. Mitigation of salinity stress on pomegranate (*Punica granatum* L. cv. wonderful) plant using salicylic acid foliar spray. Horticulturae. 8: 375.

Knight, T. G., A. Klieber and M. Sedgley. 2001. The relationship between oil gland and fruit development in Washington Navel orange (*Citrus Sinensis* L. osbeck). Ann. Bot. 88: 1039-1047.

Li, J and J. Chen. 2017. Citrus fruit-cracking: Causes and occurrence. Hortic. Plant J. 3: 255-260.

Lichter, A., O. Dvir, E. Fallik, S. Cohen, R. Golan, Z. Shemer and M. Sagi. 2002. Cracking of cherry tomatoes in solution. Postharvest Biol. Technol. 26: 305-312.

Lu, P. L and C. H. Lin. 2012. Physiology of fruit cracking in wax apple (*Syzygium samarangense*). Bot. Orient*:* J. Plant Sci. 8: 70-76.

Morgan, K. T., R. E. Rouse, F. M. Roka, S. H. Futch and M. Zekri. 2005. Leaf and fruit mineral content and peel thickness of ‘ Hamlin ’ orange. Proc. Fla. State Hort. Soc 118: 19-21.

Odemis, B., S. Turhan and D. Buyuktas. 2014. The effects of irrigation and fertilizer applications on yield, pomological characteristics and fruit cracking in nova mandarin. Agric. Water Manag. 135: 54-60.

Ohta, K. 2017. Changes in incidence of fruit cracking, yield, number and characteristics of cherry tomato cultivars developed in Japan during the last 20 years. J. Appl. Hortic. 19: 22-28.

Pham, T. T. M, Z. Singh and M. H. Behboudian. 2012. Different surfactants improve calcium uptake into leaf and fruit of ‘Washington Navel’ sweet orange and reduce albedo breakdown. J. Plant Nutr. 35: 889-904.

Razzaq, K., A. S. Khan, A. U. Malik, M. Shahid, and S. Ullah. 2013. Foliar application of zinc influences the leaf mineral status, vegetative and reproductive growth, yield and fruit quality of ‘kinnow’ mandarin. J. Plant Nutr. 36: 1479-1495.

Sallato, B., C. Bonomelli and J. Martiz. 2017. Differences in quality parameters and nutrient composition in Fukumoto oranges with and without creasing symptoms. J. Plant Nutr. 40: 954-963.

Singh, A., A. K. Shukla and P. R. Meghwal. 2020. Fruit cracking in pomegranate: Extent, cause, and management-a review. Int. J. Fruit Sci. 20: S1234-S1253.

Solanki, R., P. Mishra, D. Dadhaniya, A. M. Butani and H. P. Purohit. 2019. A chronic problem of fruit cracking in fruit crops : A review. Acta Sci. Agric. 3: 270-274.

Stander, O. P. J., K. I. Theron and P. J. R. Cronje. 2014. Foliar 2,4 D application after physiological fruit drop reduces fruit splitting of mandarin. HortTechnology. 24: 717-723.

Wang, Y., L. Guo, X. Zhao, Y. Zhao, Z. Hao, H. Luo and Z. Yuan. 2021. Advances in mechanisms and omics pertaining to fruit cracking in horticultural plants. Agronomy, 11: 1045.

Winkler, A., M. Ossenbrink and M. Knoche. 2015. Malic acid promotes cracking of sweet cherry fruit. J. Am. Soc. Hortic. Sci. 140: 280-287.

Xylia, P., A. Chrysargyris, Z. F. R. Ahmed and N. Tzortzakis. 2021. Application of rosemary and *Eucalyptus* essential oils and their main component on the preservation of apple and pear fruits. Horticulturae. 7: 479.

Xylia, P., A. Chrysargyris, D. Shahwar, Z. F. R. Ahmed and N. Tzortzakis. 2022. Application of rosemary and *Eucalyptus* essential oils on the preservation of cucumber fruit. Horticulturae. 8: 774.

Yang, Z., Z. Wu, C. Zhang, E. Hu, R. Zhou and F. Jiang. 2016. The composition of pericarp, cell aging, and changes in water absorption in two tomato genotypes: Mechanism, Factors, and potential role in fruit cracking. Acta Physiol. Plant. 38: 1-16.

Yong, W., L. Wangjin, L. Jianguo and J. Yueming. 2006. Differential expression of two expansin genes in developing fruit of cracking-susceptible and-resistant *Litchi* cultivars. J. Am. Soc. Hortic. Sci. 131: 118-121.

Zaouay, F., M. Brahem, F. Boussaa, F. M. Haddada, M. S. Tounsi and M. Mars. 2020. Effects of fruit cracking and maturity stage on quality attributes and fatty acid composition of pomegranate seed oils. Int. J. Fruit Sci. 20: S1959-S1968.

Zhang, L and G. Mingzhu. 2006. Cracking mechanism of prunus salicina and related prevention. Acta Hortic. Sin. 33: 699-704.