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RESEARCH ARTICLE

Postharvest storage of three chayote (*Sechium edule* (Jacq.) Sw.) varieties

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Abstract
The consumer demand for chayote (*Sechium edule* (Jacq.) Sw.) fruits has increased in recent years, *virens levis* being the most important variety, although other chayote varieties are gaining importance such as *nigrum xalapensis* and *n. spinosum*. However, the postharvest behavior of these varieties is different, so it is important to evaluate the factors that limit the shelf life of each variety. Therefore, in this study, fruits of each variety from the Mexican National Germplasm Bank of *Sechium edule* were used. The following fruit quality variables were evaluated: weight loss, humidity (%), color, chlorophyll, titratable acidity, total soluble solids (TSS), total sugars, and stomatal characteristics. In addition, the storage potential of each variety was evaluated for two weeks at different temperatures, 7°, 13° (85% RH) and 24 °C (60% RH), with the application of 1-methylcyclopropene (1-MCP). The variables evaluated were viviparism, disease severity, weight loss, dehydration and chilling injury (CI). The fruits of *n. xalapensis* and *n. spinosum* have a higher content of chlorophylls and carotenoids, but similar contents of TSS, acidity and total sugars than *v. levis* fruits. The use of 1-MCP reduced viviparism in all varieties, and the severity of blisters was higher in *v. levis*. The fruits of the three varieties presented severe CI when stored at 7 °C but the most susceptible to dehydration and diseases severity is *n. spinosum*.

Keywords: 1-methylcyclopropene; blisters; *nigrum spinosum*; *nigrum xalapensis*; *virens levis*; viviparism.

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1. Introduction
Chayote (*Sechium edule* (Jacq.) Sw.) is a species native to Middle America cultivated since pre-Columbian times, and it is a vegetable with wide biological diversity from Mexico to Panama. The genus *Sechium* P. Br. belongs to the Cucurbitaceae family, within this genus there are ten species, of which eight are wild: *S. chinantlense*, *S. compositum*, *S. hintonii*, *S. mexicanum*, *S. panamensis*, *S. pittieri*, *S. talamancensis*, *S. venosum and S. villosum* and two are cultivated, *S. tacaco* and *S. edule* (Barrera-Guzmán et al., 2021). Twelve varietal groups (*var.*) in common use are known in the *S. edule*, which are *albus minor*, *albus dulcis*, *albus levis*, *albus spinosum*, *nigrum minor*, *nigrum conus*, *nigrum levis*, *nigrum xalapensis*, *nigrum spinosum*, *nigrum maxima*, *amarus sylvestris* and *virens levis* which vary in size, shape, color, flavor, consistency and presence of thorns (Cadena-Iñiguez et al., 2007). In the international market, the top exporter and importer of chayote fruits is Mexico and United States respectively (Tridge, 2020). However, in recent years the demand for two varieties, *n. xalapensis* and *n. spinosum*, for the export market has increased.

The fruits of the variety *v. levis* are light green with a slight basal cleft, light green mesocarp with a neutral flavor and fiber adhering to the mesocarp, with a size between 9.30 to 18.30 cm long and 6.0 to 11.40 cm wide. The fruits of *n. xalapensis* are dark with a very marked basal cleft, and the size ranges from 5.5 to 26.6 cm in length and 4.4 to 18 cm in width. The fruits of *n. spinosum* are dark green, with high density of spines, very marked basal cleft, light green to dark green mesocarp, with a neutral to moderately sweet flavor with fiber attached to the mesocarp, and with size between 5.8 to 17.1 cm long and 5.0 to 12.2 cm wide (Cadena-Iñiguez et al., 2008).

The factors that limit the postharvest life of chayote fruits are viviparism, diseases, dehydration, and chilling injury (CI) (Aung et al., 1996; Cadena-Iñiguez et al., 2006). Viviparism is the germination of the seed within the fruit, which appears during postharvest. Seeds of chayote fruits are recalcitrant and do not show dormancy, although viviparism appears as a defense mechanism under stress conditions (pathogens attack and CI) and high humidity such as the cold storage conditions (Cadena-Iñiguez et al., 2007; García-Beltrán et al., 2021). It should be noted that chayote fruits have high moisture (86-94 %) which is necessary for the embryo development. Viviparism may be attributed to a complex interaction between growth regulators. Ethylene leads to the transcriptional activation of the genes that encode hydrolytic enzymes, which trigger the signal of abscission and finally the dissolution of the endosperm cell wall favoring germination; additionally, promote the biosynthesis and signaling of giberellins (GAs) and vice versa causing germination even when the seed is inside the fruit (Corbineau et al., 2014). Although viviparism also occurs in fruits such as papaya (*Carica papaya* L.) (Saran et al., 2014) and sapote (*Pouteria sapota*) (Cruz & Deras, 2000), where the appearance of the fruit is not affected, in chayote it represents the loss of quality.

Various studies report different methods to inhibit viviparism, such as the application of prohexadione (1 mM), an inhibitor of gibberellin synthesis (Aung et al., 2004), and 1-MCP an ethylene-competitive inhibitor that saturate receptors avoiding ethylene physiological stimulus delaying ripening and senescence; the effectiveness of 1-MCP depends on different factors like concentration, storage temperature, species and cultivar (Cadena-Iñiguez et al., 2006; Zhang et al., 2020).

On the other hand, the main diseases that attack chayote during postharvest are white freckles (*Ascochyta phaseolorum*), scabies (*Phoma cucurbitacerarum*), anthracnose (*Colletotrichum orbiculare*), reddish-purple mold (*Fusarium oxysporum*), white mold (*Phytophthora capsici*), acid rot (*Geotrichum* sp.), and cucurbit gum (*Didymella bryoniae*) (Vargas, 1988; Valverde et al., 1989; Romero-Velázquez et al., 2015). However, one of the symptoms that consistently occur in the variety *v. levis* are the blisters, caused by *Colletotrichum* sp. which manifests itself in the form of a watery pustule (Olguín-Hernández et al., 2017). There are few reports of the control of postharvest diseases of chayote. For example, Valverde et al. (1989) evaluated six fungicidal treatments against *A. phaseolorum*, *Macrophomina* sp., *Colletotrichum* sp. and *Fusarium* sp., using benomyl, thiabendazole and DF-100 (Kilol), all mixed with 1 % (w /v) alum, in fruits stored for 45 d at 12-14 °C (85%-90% RH); the best treatment was thiabendazole (300 µg mL^{-1} + alum 1% w/v) with fruit losses of 7.9% compared to the control fruits with 16.97%. Romero-Velázquez et al. (2015) isolated three fungi (*D. bryoniae*, *F. oxysporum* and *F. solani*) from chayote fruits *v. levis* and in *in vitro* experiments found that *Bacillus subtilis* inhibited their mycelial growth at LD_{50} = 0.01 mg L^{-1}, meanwhile tebuconazole and trifloxystrobin were the best fungicides for the control of *D. bryoniae* and *F. oxysporum* (LD_{50} = 0.0116 and 0.0106 mg L^{-1}, respectively) and Procloraz (LD_{50} of 0.0042 mg L^{-1}) for *F. solani*.

Fruit dehydration during storage affects the commercial quality of chayote, Valverde et al. (1989) reported that, to reduce weight losses, they used individual low-density polyethylene bags and found 8.55% compared to 14.9% of weight loss with the control after 30 d, at room temperature (19-23 °C). Cadena-Iñiguez et al. (2006) evaluated different coatings on *v. levis* chayote fruits at 6 d after storage at 10 °C, having the best results with the application of Brimex20™ wax with losses of 4.3% compared with 10% of the control fruits.

Chilling injury (CI) occurs when the fruits are stored at temperatures below their critical point, Kader (2002) recommends storing chayote fruits at 7 °C (85% - 90% RH), however, it has been observed that not all varieties respond in the same way, since in temperatures below 10 °C, lesions occur in the epidermis in the form of brown spots in *v. levis*, but there are no reports of the symptoms in other varieties (Valverde et al., 1989). Based on the above and because there is little information related to the postharvest management of chayote varieties, the aim of this work was to evaluate the characteristics of v. *levis*, *n. xalapensis* and *n. spinosum* as well as their storage behavior at three temperatures (7, 13 and 24 °C) for two weeks and the use of 1-MCP to prolong their shelf life.

2. Materials and methods

2.1 Fruit

Chayote varieties fruits (*Sechium edule* (Jacq.) Sw.): *v. levis*, *n. xalapensis* and *n. spinosum* were harvested in orchard of the National Germplasm Bank of *Sechium edule* in Mexico, the chayote plants grew under the same fertilization and irrigation conditions. The harvest was carried out in November, at horticultural maturity (18 ± 2 d after anthesis), choosing fruits without damage and transported to the laboratory within 5 h.

2.2 Experiment I. Evaluation of the physical and biochemical characteristics of the fruits

2.2.1. Fresh weight and moisture

A scale (Setra® model SI-2000S, USA) with a precision of 0.01 g was used. Weight loss was calculated for 20 individual fruits per treatment as the difference between the initial weight and the weight at the time of measurement and expressed as a percentage. For the moisture, slices of 1 cm thickness were taken from the center of the fruit, (without epidermis or seed) and placed inside a mechanical convection oven (Lab-Line Imperial V, Alpha Multiservises, Inc. USA) at 40 °C for 8 days, obtaining a constant weight.

2.2.2. Peel color. It was measured with a colorimeter (3NH TECNOLOGY CO., LTD, model NR20XE, China). Using 20 fruits per treatment, two measurements were done in the equatorial area of the fruit. The color was expressed as L, Hue and Chroma.

2.2.3. Total soluble solids (TSS). Were determined with a refractometer (Atago PAL-1®, China) with a 0% - 32% scale and expressed as °Brix (AOAC, 1994).

2.2.4. Titratable acidity. It was evaluated with 3 g of fruit tissue (pericarp and mesocarp) that was macerated with 30 mL of distilled water, and titration using 0.1 N NaOH and phenolphthalein as the indicator (AOAC, 1994). The results were reported as the percentage of citric acid (Cadena-Iñiguez et al., 2006).

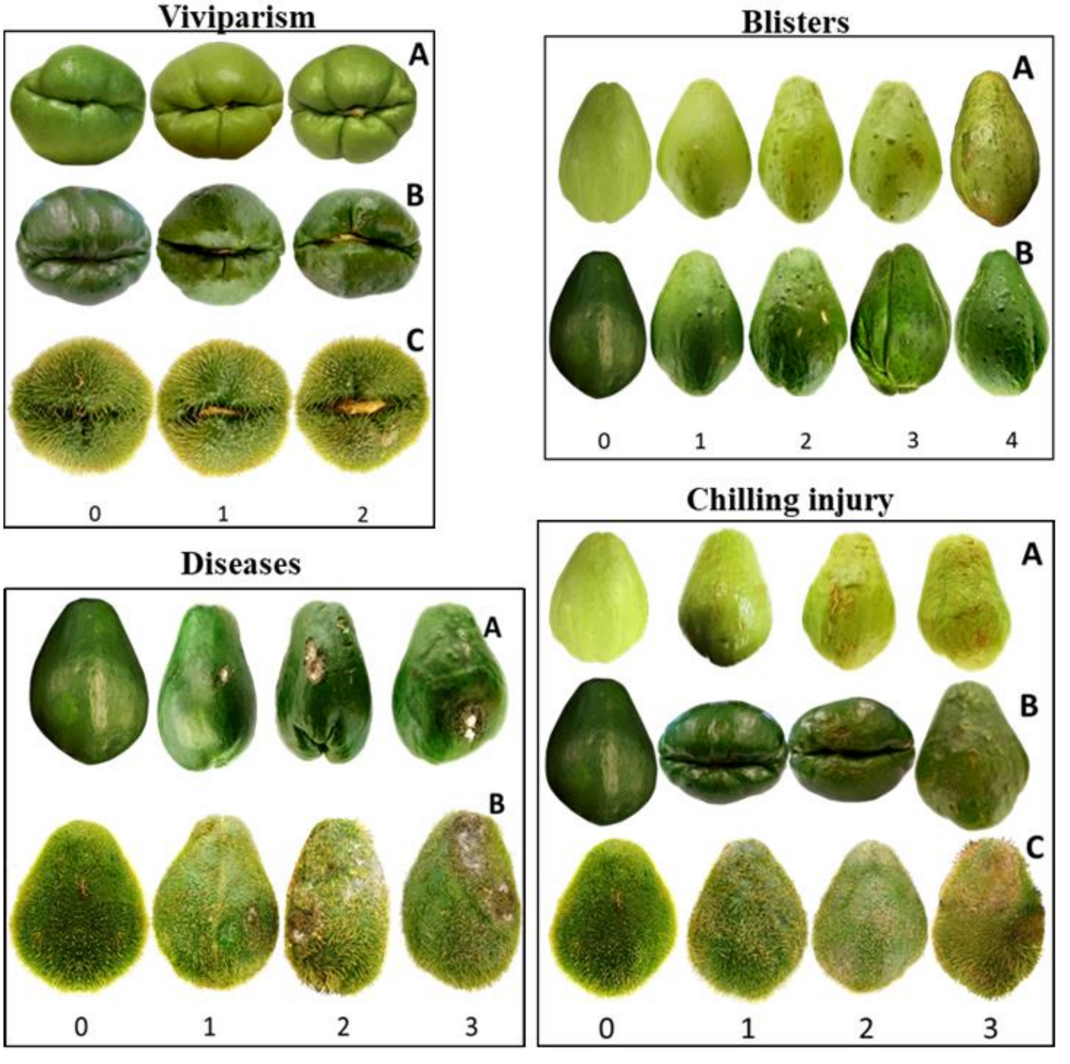

Figure 1. Chayote fruit quality rating scales. Viviparism A: *virens levis*; B: *nigrum xalapensis*; C: *nigrum spinosum*. level: 0 = no seed presence, 1 = visible seed and basal aperture and 2 = seed completely exposed. Blisters: A: *virens levis*, B: *nigrum xalapensis*. Severity levels: 0 = any blister, 1 = 1 to 5 blisters, 2 = 6 to 15 blisters, 3 = 16 to 25 blisters and 4 = 26 to 50 blisters. Diseases: A: *nigrum xalapensis*, B: *nigrum spinosum.* Severity levels: 0 = none, 1 = light, 2 = moderate and 3 = severe. Chilling injury: A: *virens levis*; B: *nigrum xalapensis*; C: *nigrum spinosum.* Incidence levels: 0 = none, 1= light, 2 = moderate and 3 = severe.

2.2.5. Chlorophyll content. It was measured by taking 2 g of the macerated fruit that were placed in a vial with a lid, 10 mL of acetone (80 %) were added and stored under dark conditions for 24 h at room temperature. Then, the extract was measured at three wavelengths: 470, 646 and 663 nm in a UV spectrophotometer (Thermo Scientific™, model Genesys™ 10UV). To obtain the concentrations of chlorophylls (mg g^{-1} fw), the equations for the 80% acetone solvent (v/v) were applied, according to Lichtenthaler (1987).

2.2.6. Total sugar content. Finely chopped chayote pulp (5 g) was placed in a flask and 60 mL of 80% ethanol was added, covering it with a piece of aluminum foil. It was left to stand for 24 h at room temperature and subsequently it was concentrated to slow boiling on a magnetic stirrer grill (Thermo Cientific ™, USA) to a volume of 10 mL. The solution was filtered with an acrodisk (Titan, 0.45 µm) and placed in a vial and analyzed by HPLC (High-Performance Liquid Chromatography) (series 200, Perkin Elmer™) with autosampler and refractive index (IR) detector. A Pinnacle II amino column of 5 mm 150 x 4.6 mm (Restek™) was used, and the mobile phase was an acetonitrile/water solution (80:20) (v/v) with a running time of 14 min. For the calibration curves, 0.05 g of fructose, glucose and 99.5 % sucrose (Sigma-Aldrich, USA) were weighed separately in 10 mL of methanol:water (1:9) (v/v), the corresponding dilutions were made (0.15 to 5 mg mL^{-1}). The conditions of the chromatograph were 35 °C, flow of 1 mL min^{-1} with an injection volume of 10 µL.

2.2.7. Size and stomata frequency. Impressions of the fruit epidermis were taken from the equatorial region, using a non-destructive micro relief technique. The fruits were washed with domestic detergent; afterwards, the selected area was cleaned with acetone at 80% (v/v). Nail polish was utilized, placing one drop on 1 cm^2 on the fruits and letting it dry for 5 min, thus obtaining a positive impression. The positive was directly observed under the optical microscope (Olympus B50, Japan).

Table 1
Fresh weight (g), moisture (%), color, chlorophyll content (mg g^{-1}), titratable acidity (%), total soluble solids (TSS) (°Bx) and total sugar content (%) in chayote fruit, varieties: *v. levis*, *n. xalapensis* and *n. spinosum*

Variety	Fresh weight (g)	Moisture (%)	Color			Chlorophyll (mg g^{-1} fw)			Total Soluble Solids (°Bx)	Titratable acidity (%)	Total Sugars (%)		
			L	Chroma	°H	C_a	C_b	$C_a + C_b$			Fructose	Glucose	Total Sugar
virens levis	343.98 ± 7.52	95.25 ± 0.53	58.34 ± 1.18	36.81 ± 0.42	106.82 ± 0.45	0.02 ± 0.005	0.01 ± 0.002	0.03 ± 0.01	4.18 ± 0.23	0.14 ± 0.001	1.09 ± 0.07	1.18 ± 0.04	2.27 ± 0.10
nigrum xalapensis	415.99 ± 1.40	93.30 ± 1.06	30.17 ± 0.48	17.89 ± 0.84	113.96 ± 0.38	0.12 ± 0.01	0.07 ± 0.01	0.19 ± 0.02	4.57± 0.08	0.13 ± 0.001	1.20 ± 0.10	1.21 ± 0.04	2.42 ± 0.14
nigrum spinosum	423.78 ± 0.72	94.65 ± 0.52	25.03 ± 0.30	16.79 ± 0.91	110.04 ± 0.80	0.11 ± 0.01	0.07 ± 0.01	0.18 ± 0.02	4.63 ± 0.32	0.14 ± 0.001	1.14 ± 0.04	1.15 ± 0.08	2.29 ± 0.06

Fresh weight (g) (n = 20 + standard error), moisture, color, chlorophyll content, total soluble solids, titratable acidity and total sugars (n = 3 + standard error). L: luminosity; C_a: Chlorophyll *a*; C_b: Chlorophyll *b*.

The number of stomata and epidermal cells were determined on each impression, in five randomly taken fields. The calculations of the stomatal index were made according to Salisbury (1928). The area of the observed field was 0.14 mm^2, obtained by measuring its diameter with a slide micrometer, visualized with the 40/0.65 lens of the optical microscope and substituting the corresponding value in the formula. The size of the stomata was obtained from the average of fifteen replicates. Finally, scanning electron microscopy (SEM) was used to observe the type and size of the stomata, and cross-sections of 1 mm were made of the exocarp of the fruit, which were fixed with 2.5% glutaraldehyde for 1 h. The tissues were subsequently washed with a Sorensen phosphate buffer (pH 7.2) for 10 min. A gradual dehydration with ethanol (100%) was carried out for 40 min and the samples were dried at a critical point with CO_2. Finally, samples were placed in the sample holders and covered with gold to be observed in a scanning electron microscope (JEOL-JSM -6300, USA).

2.3. Experiment II. Cold storage (7, 13 and 24 °C) and effect of 1-MCP on the fruit quality

Chayote fruits of each variety were stored under two cold temperatures for two weeks: 7 ± 1 °C and 13 ± 1 °C (85% RH) and room temperature (24 ± 1 °C; 60% RH), with the application of 1-MCP (0 and 600 nL L^{-1}). The fruits were washed with a 1% sodium hypochlorite solution and dried at room temperature. The application of 1-MCP was performed by placing the fruits in a hermetically sealed acrylic box and leaving a vial with the determined concentration of 1-MCP (SmartFresh®; 14%, Rohm and Haas Co.). The exposure time was 24 h at 24 ± 1 °C. Fifteen fruits per treatment were used.

A photographic quality rating scale was developed for viviparism (level: 0 = no seed presence, 1 = visible seed and basal aperture and 2 = seed completely exposed), blisters (*Colletotrichum* sp.) (severity levels: 0 = any blister, 1 = 1 to 5 blisters, 2 = 6 to 15 blisters, 3 = 16 to 25 blisters and 4 = 26 to 50 blisters), diseases (severity levels: 0 = none, 1 = light, 2 = moderate and 3 = severe), dehydration and CI (levels: 0 = none, 1 = light, 2 = moderate and 3 = severe), for each variety of chayote (Figure 1). The results were expressed as the respective index, which was calculated by adding the product of the number of fruits in each category multiplied by the score of each category and then dividing this amount by the total number of fruits evaluated.

2.4. Statistical analysis

Experiment I data were expressed as mean ± standard error, while experiment II the used using chi-square to analyze the association between the viviparism, blisters, diseases, dehydration and CI factors with the variable's temperature, treatment and variety using contingency tables. The weight loss was analyzed using a 3x3x2 factorial design (variety, temperature and 1-MCP doses) under Tukey test (α = 0.05). A hierarchical map was made using the Pheatmap package of the R-studio (version 4.0.2) program (Kolde, 2019).

3. Results and discussion

3.1 Experiment I: Characterization of the varieties

The fruits *n. spinosum* and *n. xalapensis* are 18% and 17% heavier than *v. levis* fruits respectively (Table 1). The chayote variety *v. levis* is the most known and commercially important, is exported in cardboard boxes with a capacity of 40 pounds for medium caliber (310 g approx.), with 60 pieces distributed in three layers of 20 fruits; therefore, 42 ± 2 fruits (medium gauge) per box could be packed when packing fruits of the *n. xalapensis* or *n. spinosum* varieties, stacking them in two layers due to their dimensions. In the case of *n. spinosum* fruits, the presence of thorns makes them more susceptible to mechanical damage, so care should be considered when packing.

The moisture content was higher in the fruits of *v. levis*, followed by *n. spinosum* and finally *n. xalapensis*, all above 93% (Table 1). Vegetables such as cucumber (*Cucumis sativus* L.) (Rangel et al., 2004) and pumpkin (*Cucurbita* sp.) also have moisture of 90% (Rodríguez et al., 2018). *Fusarium* sp. caused fruit rot in chayote *n. spinosum* that developed rapidly, perhaps due to the high content of water in the fruits, thin epidermis, and possible imperceptible damage caused by the spines, which facilitate the entry and development of pathogens (Montecinos et al., 2019).

The color of the fruits of *v. levis* is light green, while *n. xalapensis* and *n. spinosum* are dark green. The pigment content (chlorophylls and total carotenoids) is reflected in the color of the epidermis (Table 1). Before the 1990s, dark-skinned chayotes were the most preferred by the consumer, but later the trend changed towards lighter ones; however, in recent years the consumer has returned to the consumption of more intense colored fruits, due to interest in pigments (Avendaño-Arrazate et al., 2014).

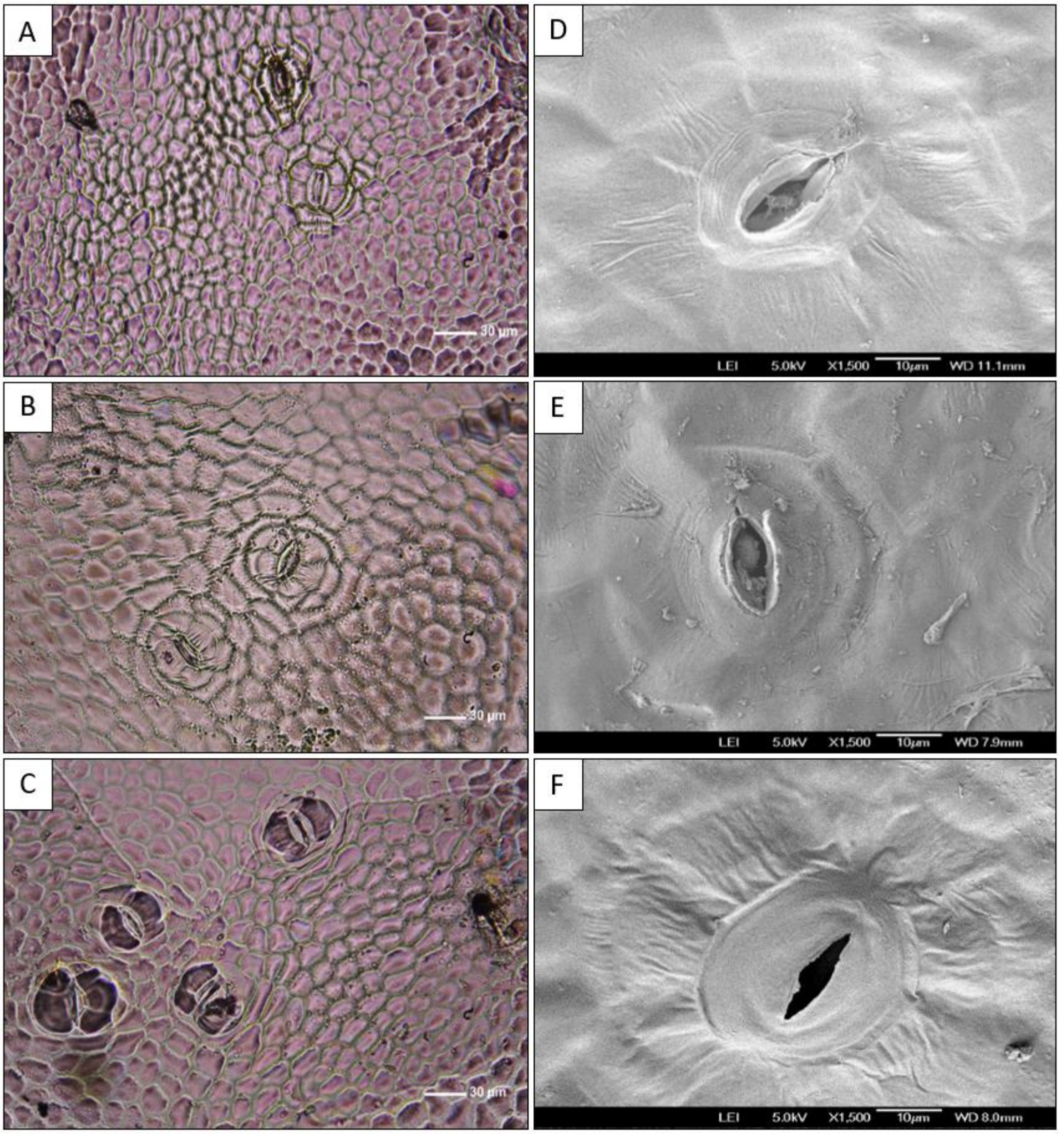

Figure 2. Fruit stomata in chayote (*Sechium edule* (Jacq.) Sw.) fruit varieties. A, D: *virens levis*, B, E: *nigrum xalapensis*, C, F: *nigrum spinosum*. Micrographs obtain under optical microscopy (A - C) and with electronic scanning microscope (D - F).

The epidermis of the fruits contains higher proportion of chlorophyll *a*, compared to chlorophyll *b*, the highest concentration is found in the fruits of *n. xalapensis* and *n. spinosum* (Table 1). Chlorophyll *a* reflects green and chlorophyll *b* a greenish-yellow color, known as accessory pigment allowing the absorption of a wider range of wavelengths. Cadena-Iñiguez et al. (2011) report 0.24 mg g^{-1} of total chlorophylls for *n. xalapensis*, 0.17 mg g^{-1} for *n. spinosum* and 0.13 mg g^{-1} for *v. levis*. Within the cucurbit family, chayote fruits have a lower chlorophyll content than other vegetables, for example, the cucumber epidermis (*C. sativus* L.) has 0.563 mg g^{-1} of chlorophyll *a*, 0.383 mg g^{-1} of chlorophyll *b* and 0.946 mg g^{-1} of total chlorophyll (Moreno et al., 2013).

Chayote fruits are non-climacteric, with a low acidity percentage (Table 1) like other cucurbits such as cucumbers (*C. sativus* L.) with values between 0.048 and 0.076% (Moreno et al., 2013). The low TSS and sugar content determine the smooth taste of chayote, with 4.18 °Bx for *v. levis*, 4.57 °Bx for *n. xalapensis* and 4.63 °Bx for *n. spinosum* (Table 1). Cadena-Iñiguez et al. (2011) report for *v. levis*, *n. xalapensis* and *n. spinosum* values of 5.14, 4.93 and 6.43 °Bx, respectively. The TSS content in other cucurbits varies, such as the case of melon (*C. melo* L.) with more the 9.0% in commercial cultivars and lower than 4.0% in traditional melon accessions (Silva-Andrade et al., 2021); while for cucumber (*C. sativus*) it is reported between 3.0 and 3.7 °Bx (Moreno et al., 2013; López et al., 2015). Each chayote variety is characterized by the flavor of its fruits: if they are slightly sweet, it is due to sugars, acids and low content of triterpenes (0.011-0.019 g 100 g^{-1}), but in wild chayote fruits the higher values of TSS (10.92 ± 0.3) are attributed principally to triterpenic compounds (0.1456 g 100 g^{-1}) (Cadena-Iñiguez et al., 2011). The sugars registered in chayote fruits of the three varieties were: glucose and fructose in similar proportions, and absence of sucrose (Table 1). Montecinos et al. (2019) recorded 2.03% of total sugars in fruits of *n. spinosum*.

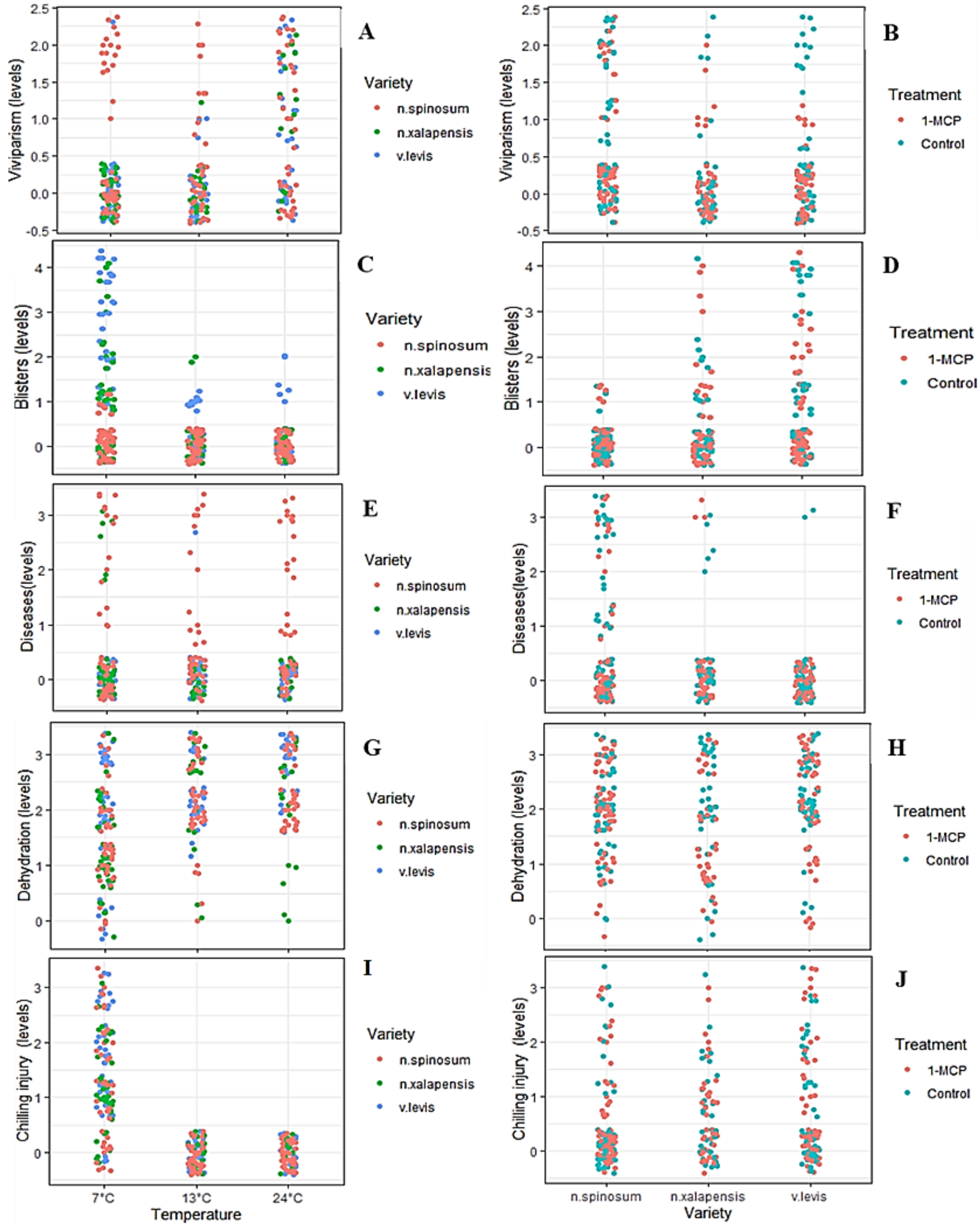

Figure 3. Frequency of viviparism (A-B), blisters (C-D), diseases (E-F) dehydration (G-H) and chilling injury (I-J) in chayote (*Sechium edule* (Jacq.) Sw.) fruits of *virens levis*, *nigrum xalapensis* and *nigrum spinosum* at day 21. The fruits were stored at 7 and 13° (14 d cold storage + 7 d after storage) and kept at 24 °C and 1-MCP (600 nL L^{-1}).

The fruit epidermis has prominent cyclocytic type stomata (Figure 2). The stomatal frequency of chayote fruits is high in relation to other non-climacteric fruits such as pitahaya (*Hylocereus megalanthus*) with 1.43 stomata/mm^2, and passion fruit (*Passiflora edulis*) with 12.64 stomata/mm^2 (Sánchez et al., 2013). In fruits, the number of stomata is defined in the anthesis and remains constant during fruit development, but as the fruit grows, the stomatal frequency decreases, as seen in *Persea americana* (Blanke, 1992).

In addition, the presence of stomata and chlorophylls in the exocarp of the fruit denotes some photosynthetic activity, which is reduced as the fruit grows. Chayote fruits are harvested in horticultural maturity at 18 ± 2 days after anthesis, so the fruit continues to grow. In addition to the development stage, the presence of stomata contributes to its weight loss, for example, in cucumber fruits (*C. sativus* L.) the presence of stomata (12.5 stomata/mm^2) on the surface of the fruit causes considerable weight loss. As observed in Table 2, the highest stomatal index occurs in the fruits of *n. spinosum*, followed by *n. xalapensis and* for *v. levis*, and in direct relation to weight loss, this is a closely related process in the postharvest physiology of fruits, since the intercellular spaces in the tissue are saturated with water vapor that comes out through the stomata (van Meeteren & Aliniaeifard, 2016).

Table 2
Stomata characteristics and weight loss in three varieties of *Sechium edule* fruits

Variety	Stomata size (µm)	Stomatal frequency (stomata/ mm^2)	Frequency epidermal cells (cells/ mm^2)	Stomata Index (%)	Weight loss (%) 7 das
virens levis	26.77 ± 0.60	26.43 ± 1.27	6161.17 ± 61.85	0.428	7.06
nigrum xalapensis	30.79 ± 0.95	27.13 ± 1.66	3042.34 ± 22.87	0.885	9.83
nigrum spinosum	34.45 ± 1.06	36.84 ± 1.86	3681.4 ± 56.49	0.989	13.08

Stomata size (n = 15 ± standard error); stomata frequency and epidermal cells (n = 9 ± standard error).
das = days after storage.

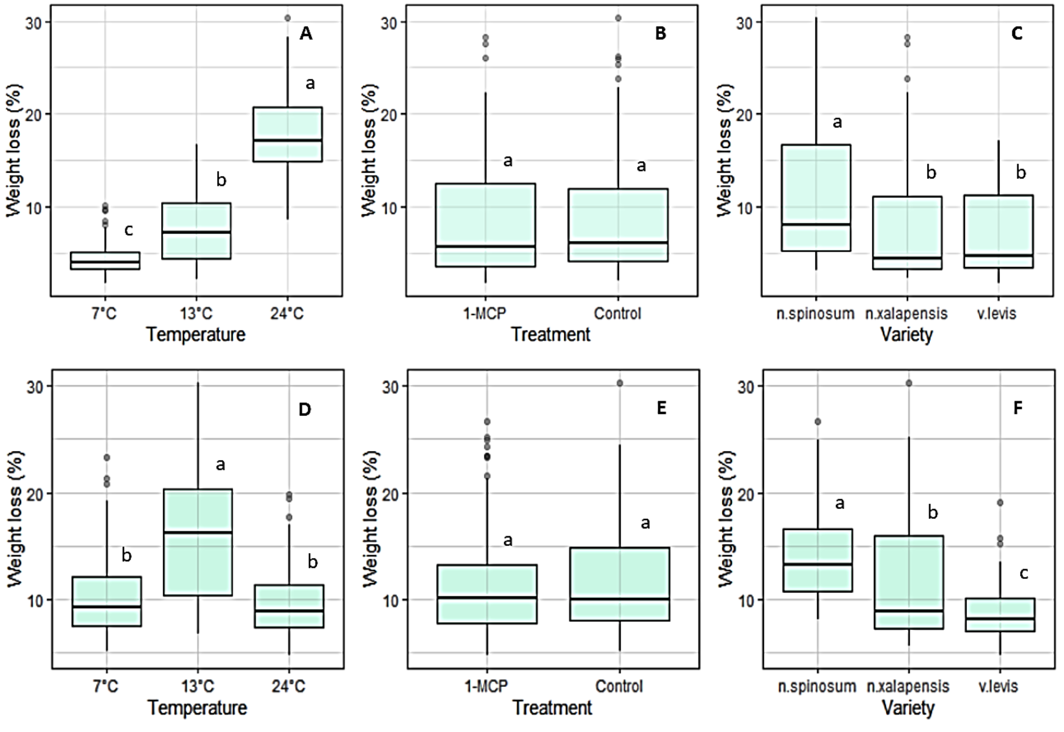

Figure 4. Weight loss of chayote (*Sechium edule* (Jacq.) Sw.) fruits of *virens levis*, *nigrum xalapensis* and *nigrum spinosum* stored for 14 d at 7°, 13° and 24 °C (A-C) and for 21d at 7°, 13° (14 d stored cold + 7 d at 24 °C) and 24 °C (D-F), with or without 1-MCP (600 nL L^{-1}). Different letters indicate significant differences ($p < 0.05$) according to the Tukey test.

3.2. Phase II: Fruit storage (7, 13 and 24 °C)

All the fruit damage rates were taken 21 days after harvest. According to the statistical analysis there is a close relationship between viviparism with temperature, variety and treatment. In the figure 3A-B it can be observed the frequencies of viviparism in the fruits of each varietal group and for 1-MCP application, as well as their behavior when storing the fruits at different temperatures. The fruits of *n. spinosum* have more viviparism at 7 °C than in those stored at 13 °C (Figures 3A, 3B). In fruits of *v. levis* this damage was slightly observed at 13 °C and in fruits of *n. xalapensis*, it did not appear until the fruits lost quality due to other factors. Viviparism appears in all varieties after 13 days at room temperature.

The low viviparism rate can be explained because the harvest was in November a period of low precipitation, because a high viviparism (70%) has been noticed during the first week of storage in *v. levis* chayote harvested in September when the rains are intense. The inhibition of viviparism by 1-MCP was evident principally in *n. spinosum* (Figure 3A), this is since 1-MCP occupies the ethylene receptors irreversibly at the membrane level, blocking the response to ethylene, in addition, the affinity of 1-MCP for the receptors seems greater than that of ethylene, however, afterwards the tissue can regain sensitivity to ethylene due to the synthesis of new receptors (Balaguera-López et al., 2021).

Cadena-Iñiguez et al. (2006) reported 30% viviparism in fruits of *v. levis* treated with 600 nL L^{-1} of 1-MCP nine days after cold storage, while the control fruits were 60%. Similarly, Montecinos et al. (2019) reported the effectiveness of 1-MCP (500 and 1000 nl L^{-1}) in fruits of *n. spinosum*, in the viviparism inhibition after storage (3 weeks at 10 °C).

Diseases caused by pathogenic fungi provoked loss of quality in chayote fruits and therefore the rejection for commercialization (Romero-Velázquez et al., 2015). The presence of blisters (*Colletotrichum* sp.) in fruits stored at 7 °C was the main problem in *v. levis* and *n. xalapensis* (Figures 3 C-D), due probably to the stress provoked by the low temperatures. The fruits of *v. levis* are highly susceptible to blisters (*Colletotrichum* sp.) which is possibly introduced to the fruit in the orchard and appear in postharvest (Cadena-Iñiguez et al., 2006; Olguín-Hernandez et al., 2017). In the chi-square test, the severity of blisters depends mainly on variety (p = 2.821 e-08) and temperature (p = 2.472 e-10) (Figures 3C and 3D). But the severity of other diseases only depends on variety (p = 3.458 e-09), been the *n. spinosum* the most susceptible.

Fruits of *n. spinosum* have a higher stomatal frequency and disease severity compared to the other two varieties; the open stomata allow the fungi to enter the fruit leading to infection in the storage period (van Meetern & Aliniaeifar, 2016). Montecinos et al. (2019) isolated from *n. spinosum* fruits, *Fusarium* sp. a highly dynamic and destructive pathogen, since it invaded the tissue quickly, but the fruits treated with 1-MCP had lower severity than the control fruits; although 1-MCP is not a fungicide, it keeps the fruit epidermis integrity because of senescence delay, which favors the resistance to mechanical damage (Gong et al., 2020), nevertheless in our results this effect was not evident (Figure 3F).

Fruit dehydration is the main problem to overcome in postharvest management of chayote (Figure 3G, 3H). This can be attributed to the functional stomata in the epidermis, which allows them to carry out gas exchange and water loss during the transpiration process and depends on environmental conditions (Barrientos-Priego et al., 2003; Cadena-Iñiguez et al., 2007). In the chi-squared test, a close relationship was observed with the temperature used (1.439 e-14). In *n. spinosum* fruits, dehydration was higher at room temperature, and more evident due to the presence of non-lignified spines; at 7 °C, *v. levis* fruits had a higher dehydration index, due to the CI. On the other hand, it is possible that the epidermis of *n. xalapensis*, being thicker, had less weight loss; this may also be associated with the stomatal index of the fruits. The stomatal index of *n. spinosum* is 57% greater than *v. levis* and 11% higher than *n. xalapensis* (Table 2). Figure 4 shows the weight loss at 14th and 21st d of storage, showing a significant difference between varieties and temperatures. The fruits lost more weight at room temperature (24 °C) and lower weight loss at 7 °C (Figure 4A), however at this temperature the fruits presented CI. Montecinos et al. (2019) report that fruits of *n. spinosum* had weight losses of 16% at room temperature at 11 days after harvest, and fruits stored at 10 °C for 3 weeks had weight losses up to 20%, showing wilted spines and loss of skin luster.

Chilling injury in chayote fruits was expressed as brown spots and small depressions, with a high correlation between variety and temperature. The most susceptible varieties to CI were *v. levis* with a marked dehydration and presence of blisters and *n. spinosum* with spines damage (Figures 3I, 3J). Meanwhile, the CI in fruits of *n. xalapensis* manifested as small depressions, but due to the dark peel color this could go unnoticed. Cadena-Iñiguez et al. (2006) reported that storage at 7 ± 1 °C and 75-80 % RH caused severe lesions in the epidermis of the *v. levis* fruits at the first week of storage, while the fruits stored at 10 and 12 °C did not show much damage. The 1-MCP did not attenuate the CI, as it has been tested in non-climacteric fruits such as oranges (*Citrus sinensis*) and climacteric fruits such as plantain (*Musa paradisiaca*) (Guillén, 2009), nevertheless Wang et al. (2010) showed in loquat a non-climateric fruit how CI susceptibility depends on cultivar and their ethylene receptors genes. Cadena-Iñiguez et al. (2006) reported in *v. levis* fruits a very low ethylene production (4-5 ng kg^{-1} s^{-1}), but no data are available for other varieties, so research about ethylene gene expression would be interesting to explain the differences in CI susceptibility.

Then according to Figure 5, fruits of *v. levis* and *n. xalapensis* are similar in terms of viviparism, diseases and weight loss. The fruits of *n. spinosum* are the most susceptible to quality loss due higher viviparism, fungi attack and dehydration, principally due to the presence of non-lignified spines. Fruits of *v. levis* fruits are more susceptible to blisters and CI, its thin cuticle and light epidermis color make the damage more evident.

4. Conclusions

The fruits of *n. xalapensis* and *n. spinosum* have higher content of chlorophylls and carotenoids, been similar to *v. levis* in TSS, low acidity and total sugars. The fruits that lose quality easily are *n. spinosum* due the spines dehydration and loss of skin luster. The use of 1-MCP reduced viviparism in all varieties, however, it did not help to reduce the disease severity and CI. The fruits of the three chayote varieties had CI when stored at 7 °C, so storage at 13 °C is recommended under modified atmosphere to reduce fruit dehydration.

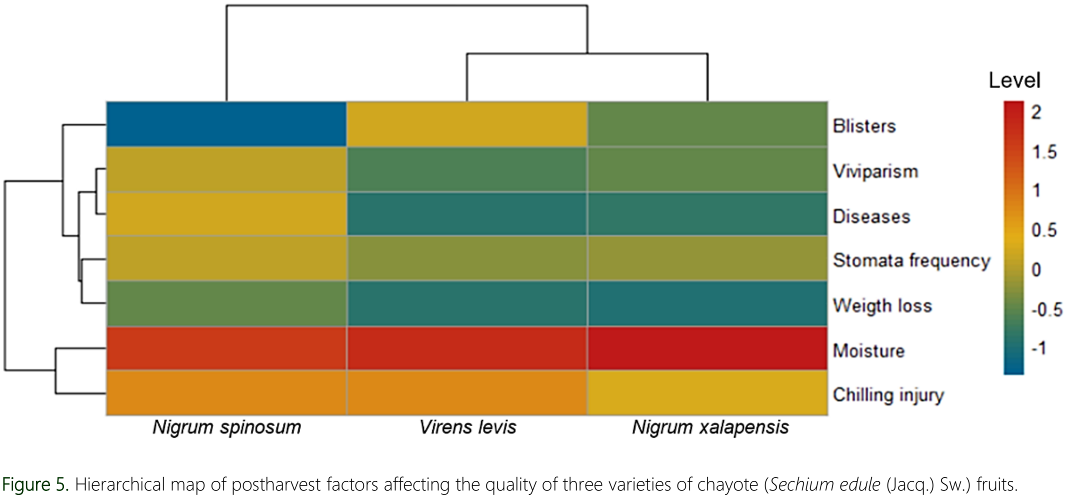

Figure 5. Hierarchical map of postharvest factors affecting the quality of three varieties of chayote (*Sechium edule* (Jacq.) Sw.) fruits.

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