LWT - Food Science and Technology 182 (2023) 114882

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Physico-chemical and microstructural changes during the drying of persimmons with different disorders. Consumer acceptance of dried slices as a criterion to valorise discards

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ARTICLE INFO

Keywords:
Persimmon snack
Dehydration
Shrinkage
Purchase intention
Consumption context

ABSTRACT

In this study, consumer acceptance of the final product is used as a criterion to evaluate the viability of valorising persimmons by obtaining dried slices from fruit that manifest different disorders: skin damage and malformations detected at harvest, and flesh browning and chilling injury manifested in astringent and non-astringent fruit during the postharvest period. During drying, slices shrunk and underwent colour changes linked with browning. In microstructural terms, the drying process was associated mainly with cell wall degradation in parenchyma tissue and cell shrinkage. Such changes were less marked in the dried slices obtained from the astringent fruit affected by chilling injury, which was linked with a higher soluble tannins content at the beginning of the dehydration process and resulted in more appealing slices. These slices completely lost their astringency during drying. The sensory study performed with 96 consumers showed that the obtaining dried persimmon slices is a promising way to valorise fruit discarded at harvest due to in-field damage and those discarded after storage due to chilling injury symptoms. Consumers liked these samples and reported 60% and 70% purchase intention, respectively. It is necessary to investigate other alternatives to valorise discards from fruit affected by flesh browning.

1. Introduction

Persimmon production has markedly increased over the last 20 years in Spain, where the cultivation area has gone from 3,518 ha in 2007 to over 16,300 ha in 2021 (MAPA, 2021). Persimmon growing is based mainly on the 'Rojo Brillante' cultivar, whose fruit are routinely submitted to postharvest CO_2-treatment to remove astringency before commercialisation.

In parallel to the rapid rise in persimmon production volume, the volume of persimmon discards has markedly increased, which implies a negative social, environmental and economic impact that has been estimated at 26% of total production. Of these, more than 10% of discards occur during harvest, when fruit with malformations or alterations associated with climate factors are discarded. Sixteen per cent of production is later discarded during the post-harvest period (Fernández-Zamudio & Barco, 2021). Two disorders linked with inappropriate postharvest handling are among the main causes of 'Rojo Brillante' postharvest losses: incidences of flesh browning and chilling injury.

The mechanical damage that fruit can endure during packing operations has been identified as the main cause of flesh browning manifestation. Packing lines may cause mechanical damages to fruit if impacts are not properly prevented by cushioning elements (Besada et al., 2010). The mechanism that lies behind flesh browning alteration has been described by Novillo et al. (2014), who determined that flesh browning affects the fruit that is mechanically impacted after removing astringency, but not astringent fruit.

'Rojo Brillante' is also sensitive to manifest chilling injury symptoms (flesh softening and pulp jellification) during cold storage (Arnal & Del Río, 2004). This disorder indistinctly affects the fruit that has been treated with CO_2 to eliminate astringency or not. Chilling injury symptoms can be delayed by applying ethylene inhibitor 1-methylcyclopropene. However, if storage is excessively long, chilling damage may occur even in 1-methylcyclopropene pretreated fruit. Moreover, this treatment cannot be applied in some cases, such as persimmons marketed according to organic production.

Currently, one of the main challenges that the persimmon industry

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https://doi.org/10.1016/j.lwt.2023.114882
Received 6 February 2023; Received in revised form 2 May 2023; Accepted 16 May 2023
Available online 16 May 2023
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faces is to search for strategies to confer the fruit that are discarded during and after harvest value. This study deals with the valorisation of persimmon discards by obtaining dried slices.

According to a recent study, dehydrated fruit is increasingly valued by consumers as a healthy snack choice with a long shelf life and as convenient food (Tarancón et al., 2021). Hot air drying is the most widely used dehydration method (Franceschinis et al., 2018), and different studies have approached the optimisation of air-drying conditions for persimmon samples in recent years (González et al., 2020, 2021; Igual et al., 2011). Therefore, air drying is presently a suitable persimmon dehydration technique.

All the above-mentioned studies have approached drying as a way to obtain a new product with a longer shelf life than fresh fruit. In them all, assays were performed with sound fruit without defects. However, drying could be a promising way to valorise persimmon discards, and the first step to make this happen is to evaluate the quality of the obtained product; i.e., to determine to what extent the different disorders that cause fruit to be discarded affect dried product properties and their consumer acceptance.

In this context, the objective of this study was to obtain dried persimmon slices from fruit affected by the main pre- and postharvest disorders that cause fruit discards, and to evaluate how these disorders affect consumer acceptance and the physico-chemical properties of dried slices. Microstructural studies were performed to evaluate the effect of disorders on the structural changes that samples undergo during drying.

2. Material and methods

2.1. Fruit samples and drying procedure

'Rojo Brillante' persimmons (*Diospyros kaki* L.*f.*) in the commercial maturity stage (31 N of firmness 20.6 °Brix and 2% dw of soluble tannins) were obtained from a packinghouse located in the town of l'Alcúdia (Valencia, Spain) on the day after harvesting. Fruit were transported to the Valencian Institute for Agricultural Research (IVIA), where they were visually inspected. One lot was formed with 30 fruit showing damages caused in the field (FiD, field-damaged fruit). In-field damage mainly included fruit malformations and skin alterations, such as sunburn browning and wind scarring. The rest of the fruit (sound fruit) were divided into four homogenous lots of 30 fruit each. One lot acted as the Control, while the other three lots were submitted to different conditions for fruit to manifest the following disorders: flesh browning (Brw), chilling injury manifested in astringent fruit (CI-Ast) and chilling injury manifested in non-astringent fruit (CI-nonAst).

To this end, the FiD, Control, Brw and CI-nonAst fruit lots were treated with 95% CO_2 for 24 h at 20 °C to remove astringency. Then 1-methylcyclipropene treatment was applied to the FiD, Control and Brw fruit lots to prevent chilling damage manifestation. Afterwards, these three lots of fruit were stored at 1 °C. Before moving fruit to a cold storage chamber, the Brw fruit was twice passed on a packing line to cause mechanical damage and to induce flesh browning disorder.

In parallel, the CI-Ast and CI-nonAst fruit lots, which were not treated with 1-methylcyclopropene to prevent chilling damage, were stored at 5 °C to induce chilling injury.

The five assayed conditions are summarised as shown below:

Control fruit: CO_2 + 1-methylcyclopropene +1 month at 0 °C
In-field damaged fruit (FiD): CO_2 + 1-methylcyclopropene + 1 month at 0 °C
Flesh-browned fruit (Brw): CO_2 + 1-methylcyclopropene + packing line + 1 month at 0 °C
Chilling-injured non-astringent fruit (CI-nonAst): CO_2 + 1 month at 5 °C
Chilling-injured astringent fruit (CI-Ast): 1 month at 5 °C

After 1 month of storage, the different fruit lots had manifested the desired alterations. Flesh browning was manifested in the Brw fruit, and both the CI-Ast and CI-nonAst fruit types manifested softening and gelling as chilling injury symptoms. The FiD and Control fruit did not show any postharvest disorder.

Once the different alterations had been manifested, 10 fruit per lot were used to determine external colour and fruit firmness. A trained panel evaluated the fruit astringency level.

To follow the air-drying process, the remaining 20 fruit per treatment were washed and transversally cut into slices (5 mm thick) with a mandolin (OXO good grips mandolin slicer 2.0, OXO, Sheffield, UK) without removing peel. The stalk and the opposite end were discarded. Based on the drying conditions optimised by González et al. (2021), hot air drying was conducted in a cabinet dryer (Model FED 260 Avantgarde. Line, Binder GmbH, Tuttlingen, Germany) at an air velocity of 2 m s^{-1} and 60 °C until 15 ± 2% water content was achieved, which took 10 h.

Flesh colour and soluble tannins were determined in slices before and after drying. Firmness and water content were measured in the dried slices. Water loss during the drying process was also determined. A sensory evaluation of the dried slices was performed by a trained panel as explained below in detail.

2.2. Physico-chemical parameters

The flesh firmness of whole fruit was determined with 10 fruit per treatment in a Texturometer Instron Universal Machine model 4301 (InstronCorp., Canton, Mass., USA) using an 8-mm plunger. The results were expressed as load in Newtons (N) to break flesh on each fruit on opposite sides after removing peel.

Soluble tannins were determined in the fresh and dried slices by the Folin-Denis method as described by Arnal and Del Río (2004). The results were expressed as % of dry weight (dw). Pulp samples were collected and frozen at −20 °C until the analysis was performed.

To determine water loss during the drying process, six slices per treatment were weighed before and after drying. The moisture content of the dried slices was determined in a Vaciotem, J.P. Selecta vacuum oven (60 ± 1 °C; pressure <100 mm Hg) after grinding 1 g of samples in a crushing machine.

The mechanical behaviour of the dried slices was measured by a puncture test with a Universal Texture Analyser (Stable MicroSystems, TA.XT2, Ltd., Godalming, UK). A cylindrical (2 mm-diameter) punch was used by applying 85% relative deformation at a distance rate of 1 mm s^{-1}. The maximum force was recorded in Newtons. Ten replicates were performed per fruit type.

The colour properties of the fresh and dried slices were obtained with a colorimeter (CR-400, Konica Minolta Inc., Tokyo, Japan) using D65 iluminant and 2° observer. The lightness (L*), chroma (C*), and hue angle (h) values (colour space CIE L*C*h) were read on four opposite points of 10 slices per fruit type. The L*, a* and b* parameters of the CIE Lab space were also recorded to determine ΔE* ($\Delta E^* = \sqrt{(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2}$), which was used to express the overall colour difference between slices before and after drying.

2.3. Microstructure

The fresh and dehydrated samples were cut into cubes (3 mm^3), which were fixed with 25 g L^{-1} formaldehyde solution at 4 °C for 16 h, dehydrated employing a graded ethanol series (500, 700 and 1000 g kg^{-1}) and embedded in paraffin (Leica, Madrid, Spain).

The obtained blocks were cut by an HM325 microtome (Microm International GmbH) in ultrathin sections (1.5 mm) and placed on glass slides. Then deparaffin slides were used and sections were stained with 0.1% toluidine blue as a staining agent. They were placed on a glass slide. Sections were bright-field-displayed with the help of a Nikon Eclipse 80i® light microscope (Nikon Co. Ltd., Tokyo, Japan) equipped with a camera (Exwave HAD, no. DXC-19, Sony Electronics Inc., Park Ridge, New Jersey, USA). Images were captured and stored at 1280 × 1024 pixels with the microscope software (NIS-Element M, version 4.0, Nikon, Tokyo, Japan).

Dried samples were also observed under a Nikon SMZ1500 stereoscopic microscope (Nikon, Tokyo, Japan) to visualise the morphology and colour of the slice surface.

2.4. Sensory evaluation

Persimmon slices' astringency level before and after drying was evaluated by a trained panel, formed by seven people used to assessing persimmon astringency and had been trained in evaluating persimmon attributes for more than 10 h. The panel consisted in four women and three men whose age range was 24–58 years. A 5-point scale was used that ranged from 1- "non-astringent" to 5 - "highly astringent".

Two evaluation sessions with the trained panel were held: one for the fresh samples and another for the dried samples. Both sessions were performed in a standardised test room. Samples were coded with 3-digit random numbers and presented monadically to panellists. Samples (one fresh/dried slice persimmon per fruit type) were served at room temperature (20 °C) in small dishes. Panellists were provided with water to cleanse their palates between samplings.

The dried persimmon slices were evaluated by 96 consumers (51% women, 47% men, 2% non-binary sex), who were recruited for being willing to participate. Samples were coded and presented following a balanced Williams' Latin square design. Consumer evaluation consisted in two parts: 1) a visual aspect evaluation; 2) a tasting test.

In the first test part, consumers were presented with the dried persimmon samples in transparent plastic bags (15 × 15 cm), which contained four slices of the same fruit type with a small label reading "Dried persimmon". They were asked to evaluate appearance liking on a 9-point hedonic scale ranging from at 1-"dislike very much" to 9-"like very much". They were also asked to provide a ranking based on their samples' visual liking so that the sample that they liked the most came in first position.

The second session part consisted of the tasting test. Consumers were provided with two dried slices of each fruit type. They were instructed to taste them and score 'in mouth overall liking', 'flavour liking' and 'texture liking' on the same above-mentioned 9-point hedonic scale. Then consumers were asked to evaluate 'global liking' and 'purchase intention' by bearing in mind how much they liked both slice appearance and in-mouth perceptions. Purchase intention was evaluated on a 5-point scale ranging from 1-"I definitely would not buy" to 5-"I definitely would buy".

When consumers had finished their tasting assessments, they were asked about the consumption context by means of the multiple-choice question "In which situations would you eat the dried persimmon slices that you have just tasted?". They were asked to select all the contexts that they considered appropriate from the following list: As part of breakfast, As a snack at home, As a snack to eat when not at home (at work, university, travelling), In a school lunch box, As dessert for lunch or dinner, As an ingredient (salad, baking, sauce, etc.), To take on a picnic, When I practise sport, As a healthy snack.

In the final section, the participants answered demographic questions about their gender and age.

The protocol and procedures used in this study were revised by the scientific directorate of the IVIA, which stated a waiver consent. All the articles from the Declaration of Helsinki and the 2016/679 EU Regulation on the protection of natural persons regarding personal data processing and on the free movement of such data were met. The experimental procedure was explained and a written consent indicating voluntary participation was obtained from each participant before the study began.

2.5. Statistical analysis

Data were subjected to an analysis of variance (ANOVA), and least significant difference (LSD) at the 5% level was used to compare the means by Statgraphics plus 2.1 (Manugistics, Inc., Rockville, Md., USA).

3. Results

3.1. Physico-chemical parameters of the fresh and dried samples

After handling fruit to provoke the evaluated disorders, the firmness of the chilling-injured fruit (CI-nonAst and CI-Ast) decreased from 31 N at harvest to values below 10 N. Higher firmness values between 20 N and 24 N were determined in the Control, FiD and Brw fruit. The soluble tannin content of fruit at harvest was 2% dw. As expected, the CO_2 treatment applied during the handling of the Control, FiD, Brw and CI-nonAst fruit resulted in lower soluble tannins content with non-astringency values (0.05% dw). Despite the CI-Ast fruit not being submitted to CO_2 treatment, their tannins significantly decreased during storage from 2% dw to 1.23% dw (Supplementary Table S1).

Flesh samples' colour was not affected by in-field damage compared to the Control because they were fruit malformations and skin disorders that were unrelated to pulp (Table 1, Fig. 1). However, the three evaluated postharvest disorders caused significant colour changes in fresh slices. The C* and h values lowered to the same extent in the Brw, CI-nonAst and CI-Ast samples compared to the Control fruit, which indicated a duller and redder colour. The postharvest disorders also led to lower lightness (L* values), but significant differences were detected among them. The lowest value was determined in the CI-nonAst samples, followed by the CI-Ast and Brw samples (Table 1).

The water content of the fresh samples was ≈84% (Supplementary Table S1). During the drying process, the initial samples' weight became lighter by ≈ 76% in all the samples. Determination of the water content of the dried slices showed no differences among samples, with a final water content of 15–17%. However, slice thickness was significantly thinner in the CI-Ast samples (1.3 mm) than in the other four samples (≈2.7 mm) (data not shown).

Persimmon slices colour underwent relevant changes during drying (Table 1, Fig. 1). ΔE* revealed that the extent of colour changes was greater in the Control, FiD and Brw samples than in the chilling-injured samples, irrespectively of the last ones being astringent (CI-Ast) or not (CI-nonAst). Thus the colour differences among the fresh samples became more evident after the drying process. Such differences in the

Table 1
Colour changes during drying. Colour coordinates of persimmon slices before (fresh) and after drying. Mean values ± standard deviation are presented. Different letters in the same column indicate significant differences among the different fruit types. * denotes significant differences between the fresh and dried samples for a specific fruit type (LSD-test, p-value = 0.05).

	Fresh slices			Dried slices			
	L*	C*	h	L*	C*	h	*ΔE**
Control	64.3 ± 2.5 d	53.3 ± 1.1 b	76.75 ± 1 b	43.2 ± 5.8 b*	45.1 ± 3.1 b*	70.6 ± 2.3 b*	23.6 ± 5.5 c
Field D.	64.8 ± 1.6 d	54.1 ± 3.2 b	77.2 ± 2.1 b	46.6 ± 1.2 b*	45.9 ± 0.9 b*	71.3 ± 1.6 b*	19.8 ± 1.9 c
Browning	58.5 ± 1.7 c	46.9 ± 4.1 a	74.2 ± 0.9 a	37.4 ± 2.4 a*	38.6 ± 2.3 a*	69.8 ± 0.6 b*	22.2 ± 2.4 c
CI-nonAst	51.5 ± 1.1 a	47.2 ± 1.7 a	73 ± 1.5 a	42.3 ± 3.1 b*	45.2 ± 2 b	66.3 ± 2.1 a*	11.9 ± 3.1 b
CI-Ast	56 ± 1.4 b	49.2 ± 1.3 a	74.3 ± 2.3 a	51.4 ± 4.3 c*	47.2 ± 3.5 b	76.2 ± 3.3 c	7.6 ± 2.9 a

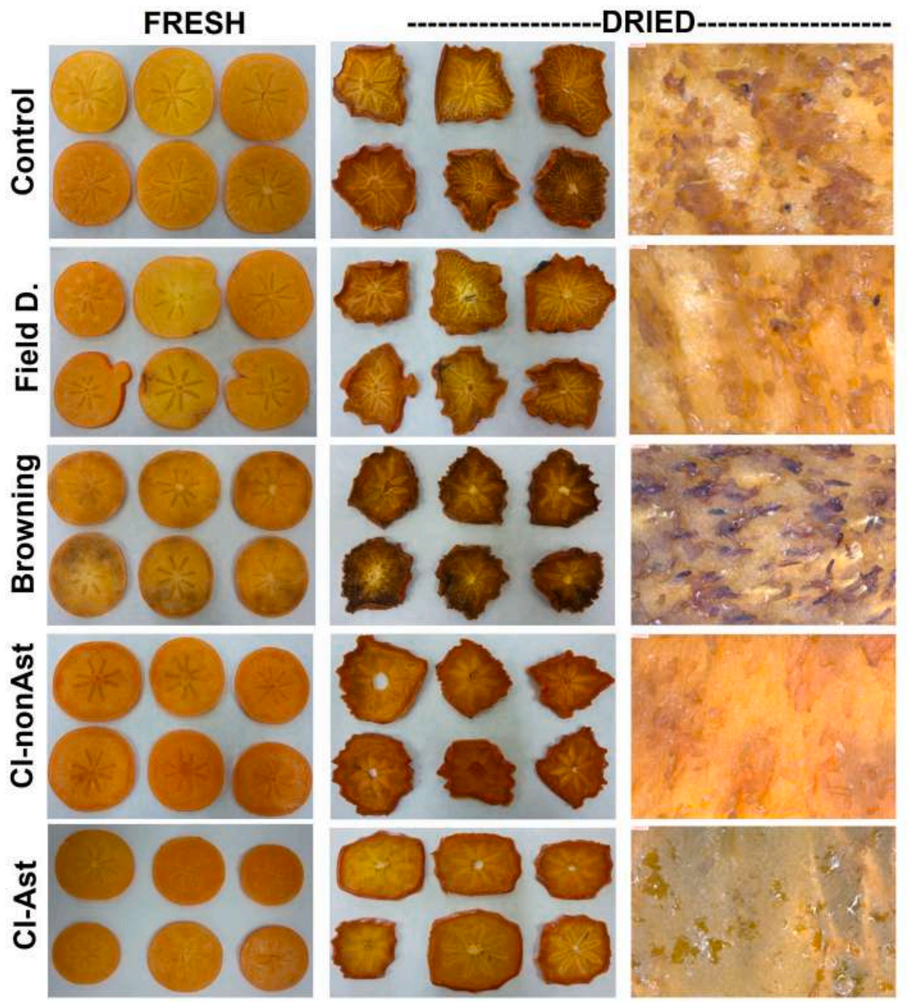

Fig. 1. Appearance of persimmon slices before and after the drying process, and images of dried slices observed under a stereoscopic microscope (1x). Control: sound fruit; Field D.: fruit with skin damage and malformations; Browning: fruit with browned flesh; CI-Ast: astringent fruit affected by chilling injury; CI-nonAst: non-astringent fruit affected by chilling injury.

dried slices were clearly visualised when observing samples under a stereoscopic microscope (Fig. 1). Drying led to loss of lightness and browning in all the samples, as reflected by a decrease in the L* values. This loss of lightness was especially evident in the Brw samples. Linked with the browning process during drying, Chroma lowered in the Control, FiD and Brw slices, but did not change in the samples obtained from the fruit affected by chilling injury. The h angle decreased in all the samples, except in CI-Ast, which indicates less yellowness after drying.

Regarding the firmness values after dehydration, the Ctrl, FiD, and Brw fruit had firmness values of around 38 N with no differences among them. The CI-nonAst slices with values of 26 N were softer. Conversely, the CI-Ast slices with values of 44 N had the hardest texture (data not shown).

3.2. Microstructure of the fresh and dried samples

Fig. 2 illustrates the microstructure images of the fresh and dried persimmons. The FiD fruit images are not shown because the structure was equal to that of the Control. Relevant differences in flesh microstructure were detected among the fresh samples. The parenchyma of the Control fruit was formed by similar sized cells, but with an irregular shape and perimeter. The presence of cells with insoluble material inside was also observed. The main difference in the structure between the fruit submitted to mechanical damage to promote browning (Brw fruit) and the Control samples was that the former are highlighted by the presence of more cells full of an insoluble material in the parenchyma. Besides, the cell size of the Brw fruit seemed more irregular than in the Control, and cell wall degradation was more marked. There are cells in which the wall is blurred, and even broken, with the consequent flow of cellular content to the outside to flood intercellular spaces. The CI-nonAst samples, which were submitted to CO_2 treatment and manifested flesh gelling as chilling damage, displayed a parenchyma structure in which the original cells' shape was mainly lost, and cells content was mixed with the wall's material. Finally, the CI-Ast samples, in which chilling damage was manifested in the astringent fruit as loss of firmness and slight jellification, had a different structure. Cell shape was less sinuous and irregular than that of the Control, and cells appeared to be somewhat more organised and turgent. Cell wall degradation started to become evident in most areas where the release of the cell wall material and intercellular spaces full of cellular material were observed. The presence of insoluble material inside cells was not evidenced in the CI-Ast samples.

After the drying process, the parenchymal cells lost their original elongated shape and became more compact due to shrinkage deformation, which was accompanied by a cell wall degradation process and, consequently, by cell content being released to intercellular spaces. Most of the characteristics that differentiated the fresh samples were still obvious after drying. Thus the Brw samples stood out for having numerous cells filled with insoluble material, while the CI-nonAst samples showed areas where the cell structure was completely lost.

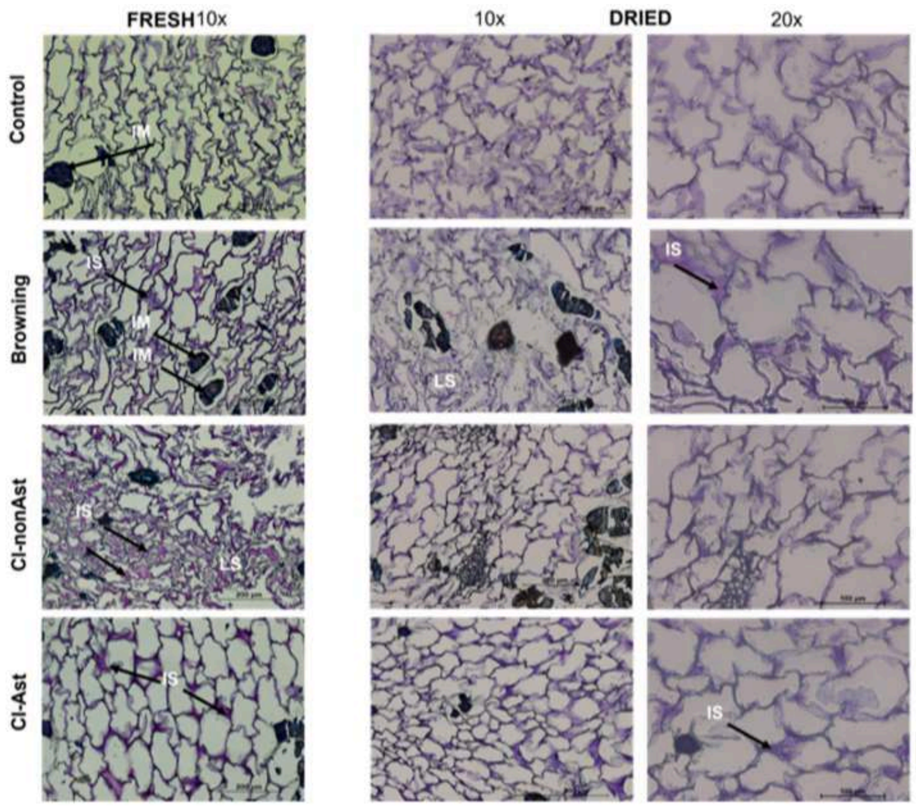

Fig. 2. Light microscopy micrographs of the persimmon slices before and after the drying process. Control: sound fruit; Browning: fruit with browned flesh; CI-Ast: the astringent fruit affected by chilling injury; CI-nonAst: the non-astringent fruit affected by chilling injury. *Insoluble material (IM), intercellular spaces with cell content (IS), lost structure (LS).*

When comparing the structure of the CI-Ast samples to that of the Control, the cells of the CI-Ast samples were more uniform in shape and had a more regular perimeter than the Control cells.

3.3. Consumer acceptability and purchase intention of dried persimmon snacks

Sample astringency was evaluated by a trained panel before and after the drying process. The panel determined that of the fresh samples, the only one that presented astringency was the CI-Ast one. In this sample type, the panellists detected a high astringency level (astringency = 5). This was an expected result because this was the only sample that was not submitted to the CO_2 deastringency treatment. After drying samples, astringency was not detected in any of them and all their scores were 1 (non-astringent). This result indicates that the CI-Ast samples lost their initial astringency during the drying process.

The results of the sensory evaluation performed by consumers are shown in Fig. 3. Consumers best liked the appearance of both the samples obtained from the chilling-injured fruit. The appearance of the CI-Ast sample was the preferred one with values over 7, followed closely by the CI-nonAst slices. Consumers gave lower scores, of around 5, to the FiD and Control samples, and reported that they disliked the appearance of the Brw samples.

Consumer preferences for the way the dried slices looked were corroborated by the ranking task results. The sample that the participants best liked was CI-Ast, followed closely by CI-nonAst. FiD came third, followed by the Control and Brw samples (Supplementary Figure S1).

When tasting slices, acceptance of the global in-mouth perception (in-mouth liking) was around 6 for all the samples. None of the four samples with disorders showed differences with the Control. However, the Brw and CI-Ast samples obtained slightly lower scores than the FiD

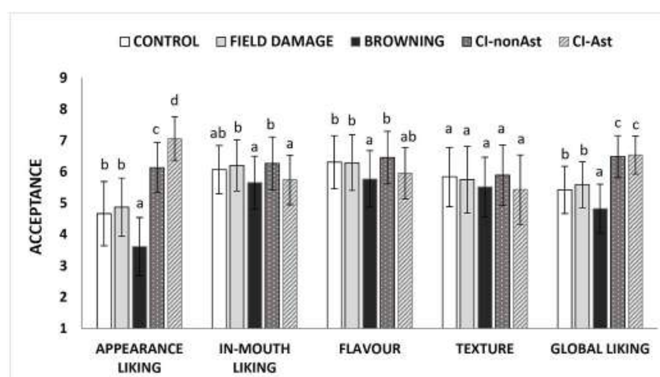

Fig. 3. Consumer acceptance of different dried persimmon snack attributes. 'In-mouth liking' refers to acceptance based on all in-mouth perceptions. 'Global liking' denotes acceptance that considers both appearance and in-mouth perceptions. Scale: 1-"dislike very much" and 9-"like very much". Error bars represent standard deviation. For each attribute, different letters among samples indicate significant differences according to the LSD-test (p-value of 0.05).

and CI-nonAst slices. When consumers were asked to score the samples based only on their flavour, the Brw slices obtained slightly lower scores than the Control ones and the other three samples. No differences were detected in the scores that consumers gave to the different samples when they were asked to evaluate their texture properties.

As a final tasting task step, consumers were asked to make a global evaluation of the sample by taking into account all their perceptions (global liking). The Control samples obtained a score of 5.5. No differences in relation to the Control were detected in the FiD slices. However, consumers liked the Brw samples less. Consumers' preferred slices were those obtained from the chilling-damaged fruit, with liking scores of around 6.5 regardless of fruit being astringent or not before being dried. This pattern of consumer preferences for the dried samples was reflected by their purchase intention (Fig. 4). Around 60% of the participants were willing to buy the Control and FiD dried slices, while only 40% would buy the Brw ones. According to their higher liking scores, the CI-nonAst and CI-Ast samples were those that most people (70%) were interested in buying.

Once consumers had finished evaluating samples, they were asked about the consumption contexts in which they would consume the dried persimmon slices that they had tried (Fig. 5). Four contexts are highlighted for being cited by more than 50% of the participants: ‘As a healthy snack’ (74%), ‘To take on a picnic’ (58%), ‘As a snack at home’ and ‘As a snack to eat when not at home’ (54%). All these contexts refer to using the dried persimmon slices as a snack to eat in different situations, and consumers attached special importance to this product’s healthy character.

4. Discussion

4.1. Effect of disorders on fresh samples’ quality

The first point to be discussed is how postharvest disorders affected the physico-chemical properties and microstructure of the fresh fruit.

In this study, the parenchyma structure of fruit at harvest was not investigated. However, previous studies into ‘Rojo Brillante’ have described its parenchyma as being quite compact with the inside of cells being almost completely taken up by a large vacuole full of soluble material and small intercellular spaces filled with air. Parenchyma cells are irregular in shape, but are basically round (Salvador et al., 2007). The fact that such a structure was not observed in any of the samples in this study is explained by the postharvest conditions to which fruit were submitted to remove astringency and/or to provoke the evaluated disorders. The effect that CO_2 has on cell membranes is well-known (Deschene et al., 1991; Makhlouf et al., 1990). Thus membranes’ weakening process linked with the CO_2-deastringency treatment applied to persimmon has been described by Salvador et al. (2007), who reported that it parallels the observation of a compact mass inside certain cells that correspond to insoluble tannins. Therefore, the irregular shape and sinuous perimeter of parenchyma cells observed in the Control fruit must be a consequence of wall and membrane weakening due to the applied CO_2 treatment.

Flesh browning was clearly observed in the fresh Brw samples both by the eye naked and microstructurally. The browning disorder has been linked with the oxidation process of tannins, which results in insoluble tannins that turn to a red-brown colour (Novillo et al., 2014). Accordingly, the microstructural observation revealed a more abundant number of cells full of insoluble material in the Brw-samples compared to the Control. Such aggregates of insoluble material were identified as the oxidised tannins responsible for browning.

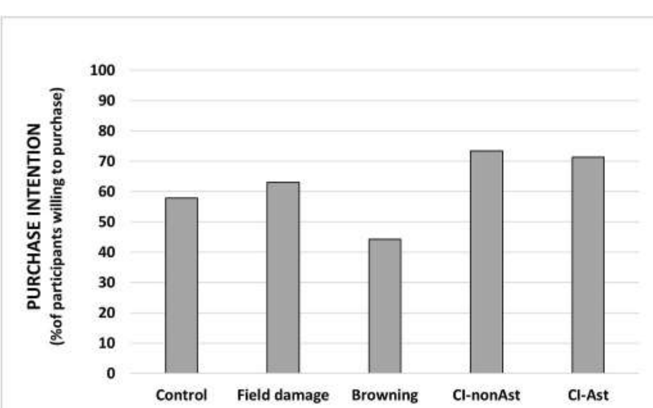

Fig. 4. Purchase intention of the different persimmon snacks expressed as the percentage of participants who stated that they would definitely/probably buy.

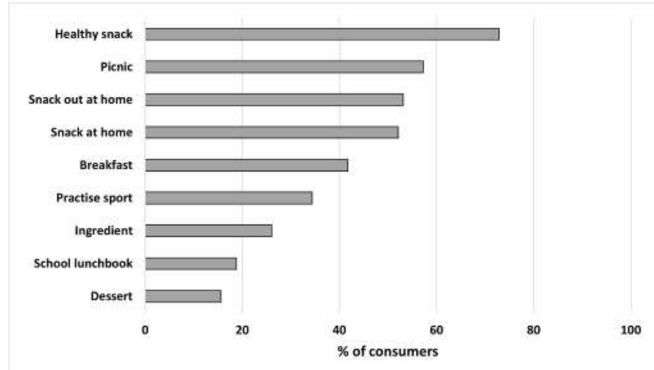

Fig. 5. Percentage of the participants who selected the different contexts to consume the dried persimmon slices.

As expected, the firmness of the chilling-injured fruit (CI-nonAst and CI-Ast) was lesser than that of the other samples. This decreased firmness was associated with pulp jellification process onset, mainly in the non-astringent fruit. Both firmness loss and jellification are common symptoms of chilling damage in persimmon, and have been associated with cell wall material degradation and loss of intercellular adhesion (Pérez-Munuera et al., 2009). This effect was mainly evident in the CI-nonAst fruit because the degradation linked with chilling damage happened on parenchyma tissue that had already been weakened by CO_2 treatment.

Besides the higher degradation level detected in the CI-nonAst fruit compared to the CI-Ast ones before drying, another relevant difference, and probably the most important one between these two samples, was the higher soluble tannins content present in the fruit not submitted to CO_2. In fact when the trained panel evaluated the fresh slices, the CI-Ast fruit was the only one in which panellists detected astringency. However, it is important to mention that the soluble tannins in the CI-Ast fruit significantly decreased during low-temperature storage, which has been previously associated with chilling injury manifestation (Rasouli & Khademi, 2018; Tessmer et al., 2019). This is the reason why CI-Ast was the only fruit that we assayed with no previous CO_2 treatment application because we expected a partial reduction in soluble tannins linked with chilling damage, which was not expected in the other samples.

4.2. Changes in samples during the drying process

Loss of water during the drying process was the same in all the samples, and the final water content (15–17%) was in accordance with that reported by González et al. (2021), who applied similar drying conditions to persimmon slices. However, the thickness of the dried CI-Ast slices was thinner than in the other cases, and we related this difference in thickness to the final slice shape and microstructural changes during drying. As observed in Fig. 1, the dried CI-Ast slices were isodiametric in shape, which was a similar shape to that of the fresh slices, while the slice perimeter of the other four samples was sinuous. As we did not expect any slice shrinkage differences when planning the study, we did not measure the diameter of slices before and after drying, which would have been very interesting. However, the data of the thickness of the dried slices, together with their visual observation, allowed us to affirm that slice deformation and shrinkage during the drying process were clearly less marked in the CI-Ast samples. This fact suggests that the structural changes undergone by the CI-Ast samples during the drying process were, to some extent, different from those of the other samples, which we corroborated at the microstructural level.

Zhao et al. (2021) reported that parenchyma cells shrink during persimmon drying, which leads to cell shape deformation. The microstructural observation performed in the present study allowed to visualise this phenomenon. It revealed that of the five evaluated sample types, the CI-Ast samples stood out for their less accused parenchyma cell shrinkage. Hence the less marked shrinkage at the cellular level of the CI-Ast samples would explain why, compared to the other samples, the size and shape of the CI-Ast-dried slices were more similar to those of the original fresh slices; namely they underwent fewer changes during drying. We should also bear in mind that the CI-Ast samples were also those that underwent fewer colour changes and had higher firmness values after drying. When comparing CI-Ast to the other samples, these differences in drying-related changes were explained by the properties of the different samples before they were dried; i.e., by the fresh samples' properties.

The main difference in the CI-Ast fresh samples in relation to the others was their higher soluble tannins content, which suggests that they are responsible for the observed differences. Here we discuss the mechanism that likely lies behind this.

During the drying process, the soluble tannins of the CI-Ast samples drastically dropped to reach non-astringency values that equalled those of the fruit submitted to CO_2. Astringency loss during persimmon drying has been previously reported by González et al. (2021) who, after obtaining dried slices from astringent fruit in three maturity stages, found that in the most advanced stage, astringency drastically reduced after drying. According to the aforementioned study, astringency reduction during drying depends on the initial fruit stage. Our results showed that the fruit which manifested chilling injury symptoms during dehydration had completely lost their astringency.

Different studies have demonstrated that persimmon astringency may be reduced by the complex formation between pectin and tannins. Taira et al. (1997) explained that the reduction in astringency that parallels persimmon softening during storage at 20 °C is due to pectin-tannins interactions. Later Hayashi et al. (2005) confirmed loss of astringency in tea mediated by tannins-pectin complexation. On the other hand, Oshima et al. (2021) reported a marked increase in water-soluble pectin while drying persimmon samples. According to the studies of Le Bourvellec et al. (2004) and Mamet et al. (2018), one of the main components of cell wall polysaccharides, pectin, possesses high affinities to tannins because of the formation of hydrophobic pockets that can encapsulate tannins, which is controlled mainly by cooperative hydrogen bonding and hydrophobic interactions. Therefore, it is quite likely that pectin-tannins complexation played a significant role in the astringency loss herein observed during the drying process of the CI-Ast samples.

The pectin-tannins interaction may also explain the lesser deformation undergone by the dried CI-Ast slices compared to the other samples. Mamet et al. (2017) compared the reaction ability of small *versus* large persimmon tannin molecules with pectin, and found that smaller tannins may more easily cross-link with pectin through hydrogen bonds and hydrophobic contacts, which leads to higher formed gel strength. Based on the results of the aforementioned study, tannins in a soluble form (CI-Ast), which are smaller in size than the insoluble ones (Ctrl, FiD, Brw and CI-nonAst), should generate more bounds with pectin and strengthen the resulting structure, which would alleviate the shrinkage event during drying. This fact would also help to explain the higher firmness values for the CI-Ast slices compared to the other samples.

The differences found in the final colour of the dried slices must also be associated with the higher soluble tannins content of the CI-Ast samples at the beginning of the process. Our results showed that all the slices underwent a certain level of browning during drying, but the extent of this very much depended on sample type. The CI-Ast sample slices were those that displayed fewer colour changes during the drying process, with no changes in the C* and h parameters. After studying the role of soluble and insoluble tannins in the browning of dried persimmons during storage, Zhou et al. (2022) reported that insoluble tannins contributed preponderantly to browning, while soluble ones barely contributed. Fruit browning is linked mainly with oxidative enzymatic or non-enzymatic processes, and the soluble tannins of 'Rojo Brillante' persimmon have been shown to have a much higher antioxidant capacity than insoluble ones. Thus one collateral effect of CO_2 treatment is loss of antioxidant properties (Besada et al., 2012). Therefore, the soluble tannins present in the CI-Ast fruit, with good antioxidant capacity, must help to hinder the oxidative processes linked with sample browning during drying.

4.3. Relation between dried slice properties and consumer acceptance

When consumers were asked about their global acceptance by taking into account all the sample attributes, the preferred dried slices were those obtained for the chilling-damaged fruit. The evaluation of the different attributes (appearance, flavour, texture) revealed that fruit appearance played a key role in global liking. The CI-Ast samples were the most appealing to consumers, followed by CI-nonAst ones. Such preferences were linked with dried slice colour because these two samples were those that presented less browning during drying. The CI-Ast samples also had a more isodiametric shape, which likely contributed to being the preferred ones. On the contrary, the Brw snack was liked the least, which was related to its dark brown colour.

The characteristic malformations and skin damage of the fresh FiD fruit became less evident after drying and did not affect consumer acceptance compared to the Control.

It is important to mention that the differences in structure and firmness detected in the CI-Ast samples did not affect how much consumers liked their texture upon tasting. Equal scores for samples do not necessarily imply perceptions of the same texture properties, but what they do imply is that the texture perceived upon eating different samples is equally liked. Our results open the door to further studies with trained panels to determine if the different structure of the CI-Ast snack, compared to the others, is reflected in the sensory perception of specific texture attributes, such as hardness, cohesiveness, etc.

5. Conclusions

According to our results, obtaining persimmon dried slices is a promising way to valorise persimmons discards at harvest due to in-field damage (malformation, sunburn, wind scarring), and those discarded after storage due to chilling injury symptoms (softening and gelling). Consumers were interested in this product to mainly consume it as a healthy snack. They liked the dried slices obtained from in-field damaged fruit as much as those obtained from sound fruit. Furthermore, the slices obtained from the chilling-damaged fruit obtained higher liking scores than those obtained from the Control fruit. This was mainly due to the more appealing aspect of the dried slices obtained from the chilling-damaged fruit, mostly the fruit that was not submitted to the CO_2-deastringency treatment. It is necessary to investigate other alternatives to valorise discards of fruit affected by flesh browning because the consumer acceptance of the dried slices obtained from this fruit was low.

Physico-chemical studies revealed the main changes associated with water loss during drying, mostly changes in colour and slice shrinkage. In microstructural terms, the drying process was associated mainly with parenchymatic cell wall degradation and cell shrinkage. Of the evaluated samples, those affected by chilling injuries when astringent, i.e. the CI-Ast fruit, are highlighted for undergoing the above-mentioned changes, but to a lesser extent. It underwent less browning and shrinkage, with resulted in dried slices looking more appealing. Such differences during drying in relation to the other samples are linked with the higher soluble tannins content of the CI-Ast fruit at the beginning of the drying process.

CRediT authorship contribution statement

Empar Llorca: Conceptualization, Formal analysis, Investigation. **Ana Pons-Gómez:** Writing – original draft, Investigation. **Cristina Besada:** Conceptualization, Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare no conflicts of interest.

Data availability

Data will be made available on request.

Acknowledgements

Author Ana Pons-Gómez wishes to thank the Regional Ministry of Innovation, Universities, Science and Digital Society (Generalitat Valenciana) for the financial support of her contract EDGJID-2021-252. This work was supported by Project IVIA-GVA 52201 from the Instituto Valenciano de Investigaciones Agrarias (this project is cofinanced by the European Union through ERDF Program 2021-027 Comunitat Valenciana).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2023.114882.

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