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Consumer perception and physicochemical characterization of a new product made from lactic acid fermented orange peels

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ABSTRACT

A new product made from orange peels discarded from juice making has been characterized during the present study. In order to reduce its bitterness, orange peel was fermented during 10 days in two different sugary brines (2% or 5% NaCl content) using a *Lactiplantibacillus plantarum* strain. The lactic acid fermentation process was characterized by determining pH, sucrose, and the organic acids content. The original peel and the final products were characterized by instrumental texture and color determination, and total flavonoids content. In addition, consumers' expectations and perception of the new products were also studied using an online survey and a consumer study in which acceptance and perceived bitterness were assessed. Results suggested that the 2% NaCl-fermentation process allowed a greater bacteria development (with a higher lactic acid production and larger differences in color parameters with the original peel than the 5% NaCl-fermented samples) although both fermented samples were significantly different from the original peel in their physicochemical characteristics. Total flavonoids content, which has been related to bitterness perception, was significatively lower in the fermented samples than in the raw orange peel (50% reduction). Spanish consumers' expectations and perception of the new product were similar, and the snack made with the peel fermented in the 2% NaCl-brine was more liked than the same snack made with the original peel, or the 5% NaCl-fermented one. Using a lactic acid fermentation in a sugary brine was useful to decrease the bitterness perception and increase liking of the orange peel, meaning a potential valorization for this orange juice by-product.

Implications for gastronomy.

The present study includes the physico-chemical characterization and consumers' perception of a new product developed with one of the main citrus by-products: orange peels. A new ingredient for the Spanish gastronomy is proposed, showing a potential use for one of the main HORECA (HOtels REstaurants Catering sector) and juices industry by-products. A simple lactic-acid fermentation process, inspired in the North-African gastronomy culture, is described, and the consumer perception of the new product, presented as a freeze-dried snack is shown, proposing a new way of decreasing this food waste in Spain. In addition, some ideas about how to decrease bitterness perception on flavonoids-rich materials are shown, contributing to the knowledge on other new foods development.

1. Introduction

The Spanish Ministry of Agriculture, Fisheries and Food has estimated a citrus production in Spain of 6.705 million t for the 2021/2022 campaign, orange fruits being approximately 54% of the total (MAPA, 2021). The production of oranges has increased worldwide during the last 10 years (FAO, 2020) and, therefore, the waste associated to the orange processing industry has also increased. Management of the different citrus industry by-products has been extensively investigated, and different forms of upcycling have been proposed, such as pectin extraction (Alamineh, 2018), cellulose extraction (Bicu and Mustata, 2011), bioethanol and other biorefinery products obtention (Ayala et al., 2021; Fazzino et al., 2021; Siles López et al., 2010); but its main destination remains being cattle feed, composting, or incineration/dump disposal (de la Torre et al., 2019). Therefore, most of the proposals for valorizing orange peel are based in expensive biorefinery processes,

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although it is an edible byproduct with a significant content of different micronutrients and minerals such as vitamin C, flavonoids, iron, and copper (USDA, 2019; Genovese et al., 2014; Czech et al., 2019).

Different parts of citrus fruits including peels, pulp, or seeds are consumed in fresh or dried forms in some gastronomy cultures, being popular in for example traditional Indian Ayurveda and Siddha medicines as well as other Oriental medicines (Sharma et al., 2018). One of the main problems for the citrus fruits industry, and which has an impact on the potential consumption of the aforementioned citrus parts, is bitterness, generally associated with a high concentration of flavonoids (e.g.: limonin or naringin), which are present mainly in immature fruits or fruit peels (Hasegawa et al., 1996; Purewal and Sandhu, 2021). These compounds have been reported to have a wide range of biological activities such as anticarcinogenic, lipolytic, or analgesic (Sharma et al., 2018). Therefore, although bitterness could be a problem for the acceptance of orange peel derivative products, it may be interesting to maintain the flavonoids present in citrus peels from a health/functional perspective.

Different strategies have been proposed to reduce bitterness perception in food and beverages, including the use of strong flavors or tastings (e.g.: salt, sweeteners, acid) (Ley, 2008). Dea et al. (2013) described a decrease in the perception of the bitterness induced by limonin and nomilin in orange juice when sucrose was added to the juice. Raghuvanshi et al. (2019) investigated the concentration of flavonoids during the fermentation process of different vegetables (beets, carrots, peppers, radishes) in 5% NaCl brines, detecting great differences in their evolution depending on the matrix, but orange was not studied during their research. Deba-Rementeria et al. (2021) used orange peel discarded from juice production to make orange *msayer*, a fermented product inspired in the typical Moroccan/North African "pickled" lemons and which have been reported to have a low bitterness (Aayah et al., 2010; Bousmaha et al., 2006). Yıldız Turgut et al. (2016) studied 19 different debittering methods for orange peel used in jam production, highlighting among them: water blanching, blanching in water with a 4% NaCl, and blanching in 1% Na_2CO_3. The orange peel product developed by Deba-Rementeria et al. (2021) was considered too salty when a 15% NaCl brine was used during fermentation, but seemed to be perceived less bitter than the products fermented in 10 or 5% NaCl brines. Later research on fermented orange peels suggested using blanching and a driven fermentation to accelerate the process (Deba-Rementeria et al., 2022). Although sensory analyses were not conducted in this study, the other aforementioned investigations seemed to suggest that blanching, salt addition, and some fermentative processes may be useful to reduce bitterness in fruits and vegetables.

The aim of the present research was to characterize and determine consumer's expectations and perception of a new product made from blanched and lactic acid fermented orange peels, which were processed using a *Lactiplantibacillus plantarum* strain in two sugary brines (both of them with 3% sucrose, and 2% and 5% of NaCl respectively). A reduction of the previously reported 5% NaCl content (Deba-Rementeria et al., 2021) was studied because up to a 20–50% reduction in NaCl has been suggested to improve traditional fermented products from a health perspective (Lin et al., 2021).

2. Material and methods

2.1. Reagents

Ultrapure water (Type I, 18.2 mΩ-cm) was from an Elga Purelab Flex 3 (ELGA LabWater, UK). Sodium chloride (99,9%) and sucrose (99%) for the brine, were supplied by VWR, (VWR Inc, Germany) and Panreac AppliChem (Panreac AppliChem, Barcelona, Spain), respectively. Sulfuric acid (95%, 0.3 g L^{-1}) for HPLC analysis was supplied by VWR, (VWR Inc, Germany) while sucrose, and lactic and acetic acid were from Sigma Aldrich (HPLC grade; Merck KGaA, Darmstadt, Germany). Peptone saline solution and Man, Rogosa and Sharpe (MRS) agar were from VWR, (VWR Inc, Germany). For total flavonoids determination, hesperidin (≥80%) and diethylene glycol (99%) were supplied by Sigma-Aldrich (analytical grade; Merck KGaA, Darmstadt, Germany) and methanol (HPLC grade) from VWR, (VWR Inc, Germany).

2.2. Orange samples

Orange (*Citrus sinensis*, Navel Lane late cultivar) peels discarded from making orange juice in the Basque Culinary Center restaurant (Basque Country, Spain) were used for the present study. The juice was made in a Zumex V machine (Zumex®, Valencia, Spain) and the unused de-juiced whole peels (including albedo and flavedo, but removing pulp remaining if still present) were cut in 2 × 2 cm pieces. Peels which were significantly damaged by the machine, or had irregular shapes, were discarded. Once cut, to remove competitive microbiota and easy the lactic fermentation process (Breidt et al., 2000), as well as to potentially contribute in the debittering task (Kore and Chakraborty, 2015), peels were blanched during 10 min in boiling water.

2.3. Lactic acid fermentation characterization

Fermentation of orange peels was performed in 500 mL tank vessels of a 4-biorreactor station Biostat Q® (Braun Biotech International, Melsungen, Germany) equipped with a DCU 3 control unit which recorded temperature and pH data.

The L. *plantarum* CECT 749 strain (Spanish Collection of Type Cultures, Valencia, Spain) was cultivated and maintained according to the rules of the collection (MRS broth, 37 °C, 24 h). *L. plantarum* is a facultative heterofermentative bacteria commonly isolated and used in different vegetable and fruit fermentations (Ricci et al., 2019; Swain et al., 2014). Bacteria concentration was measured by Plate Count Agar (PCA) method (ISO 4833–1:2013) (AENOR, 2014) and adjusted to 10^4 UFC mL^{-1} with sterile water to inoculate 2 mL in the sterile 2% or 5% NaCl brines. Furthermore, brines were also supplemented with 3% sucrose (w/v) as suggested by Deba-Rementeria et al. (2021). Then, the previously sterilized fermentation vessels were filled with 175 g of the blanched peels and covered with the corresponding brine and 1 cm of sunflower oil. The oil layer was used to imitate the traditional making process and to the keep anaerobic conditions (Aayah et al., 2010; Deba-Rementeria et al., 2021). Temperature was maintained at 21 °C during the 10-days process. Each NaCl concentration condition (2% and 5%) was replicated in 2 different vessels, therefore, all subsequent analyses were conducted in duplicate.

Sucrose consumption and the organic acids released to the media during the fermentation process were analyzed by daily sampling the brines, while pH was recorded automatically by the system probe. Brines were sampled and filtered using a 0.2 μm cellulose acetate filter (Sartorious, Merck KGaA, Darmstadt, Germany) before their injection in a High-Performance Liquid Chromatograp (HPLC; Agilent, model 1200, Palo Alto, CA). The HPLC was equipped with an Aminex HPX-87H ion exclusion column (Bio Rad 300 × 7.8 mm, 9 μ particles) and a guard column and a refractive index detector. A method of 0.3 g L^{-1} of sulfuric acid at a flow rate of 0.6 mL min^{-1} at 50 °C was used as reported by Paz et al. (2019). Calibration curves for sucrose and lactic and acetic acids were used to quantify the samples' concentrations.

2.4. Lactic acid fermented orange peels characterization

2.4.1. Physicochemical analyses

Extractives (nonstructural components that can be extracted by solvents such as fats, waxes, proteins, terpenes, gums, resins, simple sugars, starches, phenolics, essential oils, pectins, mucilages, glycosides and saponins, fatty acids, sterols, and flavonoids; Kallioinen et al., 2003), moisture, ash content, structural carbohydrates, and lignin of blanched orange peels samples (OP) and the fermented samples (F) were characterized following the procedures for biomass of the National

Renewable Energy Laboratory (NREL) (Sluiter et al., 2008, 2012). This general characterization was complementary to the determination of the physico-chemical properties that may be related to the organoleptic ones (color, texture, and flavonoids content) and could have a significant impact on products' acceptance.

The color of the OP and the F samples was measured with a Chroma Meter CR 400 (Konica Minolta, Inc, Japan) using the CIE $L^*a^*b^*$ color space and an illuminant D65 and a 10° observer as references. Data were expressed with the L^*, a^*, b^* values and, then, the total color change (ΔE) of the F samples was calculated: $[\Delta E^* = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2}]$, being OP samples' values L_0^*, a_0^*, b_0^* (Cserhalmi et al., 2006). Chroma $[C^* = (a^{*2} + b^{*2})^{1/2}]$ and Hue angle $[H = \tan^{-1}(b^*/a^*)]$ were also calculated. Twenty measurements were recorded for each sample.

The conditions reported by Deba-Rementeria et al. (2021) for orange *msayer* hardness measurement were used to determine the OP and F samples hardness. The pieces, already with a 2 × 2 cm shape, were cut with a HDP/BSK blade set probe (Warner-Bratzler with rectangular slot blade) in a Texture Analyzer Aname (Microstable system, UK). Force was measured by a 30-kg loadcell, the maximum capacity of the instrument was about 300 N, and the cut was made at a speed of 1 mm s^{-1}. Peak cutting force was considered as the first peak force in g. A total of 15 replications were carried out for each sample.

Finally, total flavonoids of the samples, which could be related to bitterness, were determined using the extraction procedure and modified Davis method reported by Huang et al. (2018). Following these authors recommendations, hesperidin was chosen as the standard compound for the calibration curves, and a wavelength of 360 nm was used for absorbance measurement in a UV–Visible spectrophotometry equipment (UH5300 Spectrophotometer, Hitachi, Japan). This Davis Method was chosen because it has been recommended as a measure of the relative decrease in bitter flavonoids during a debittering process (Hasegawa et al., 1996).

2.5. Consumer perception: expectations and sensory evaluation

The protocol for the consumer study was approved by the Basque Culinary Center scientific committee, which stated a waiver consent (BCC21/0809). All articles from the Declaration of Helsinki and the 2016/679 EU Regulation on the protection of natural persons regarding the processing of personal data were met. Consumers were recruited from the Basque Culinary Center consumers' database.

Pickled fruits and vegetables can be consumed in different formats, being ingredients in different dishes or salty snacks in Mediterranean cultures. To ease preservation and present the new product in a format somehow familiar to Spanish consumers, the OP and F samples were freeze-dried (24 h, 0.200 mBar, −50 °C) (Lyoquest −55 Telstar Technologies S.L.U., Spain) to make a "dried fruits-like snack" before the consumer study. Then, an online survey (n = 289) was conducted to investigate consumers' knowledge and expectations about fermented products and about the new fermented product. The survey included different questions related to:

a) General knowledge about fermented foods. First, respondents had to answer a question to freely mention 5 foods from the Spanish gastronomy in which they thought that fermentation was used. Then, 3 Check-All-That-Apply questions (CATA) were included to: 1) indicate all the different terms that respondents associated to the concept 'fermentation', 2) indicate all those raw materials that respondents would consider appropriate for developing fermented foods, and 3) mark the main reasons for using fermentation, from a consumer perspective.
b) The expected liking of a '*freeze-dried-fermented orange peel snack made from peels discarded from orange juice making*' using a 9-points hedonic scale (1 = dislike extremely, 5 = neither like, nor dislike, 9 = like extremely).
c) A CATA question to mark the sensory attributes that respondents expected to find in a *freeze-dried-fermented orange peel snack.*

Then, a consumer test (n = 61) was carried out to determine the acceptance and bitterness perception of the fermented peels *vs* just blanched orange peels. Consumers had to be over 18 years old and willing to taste fruit snacks. Participants had to rate liking of the 3 freeze-dried snacks (OP, and fermented OP in a 2% and 5% brines) using a 9-points hedonic scale (1 = dislike extremely, 5 = neither like, nor dislike, 9 = like extremely) for the attributes appearance, flavor, and texture. In addition, saltiness and bitterness perceptions were assessed in a 190 mm general Labeled Magnitude Scale (gLMS) developed for taste intensity comparisons among individuals, and with labels from "barely detectable" to "strongest imaginable" (Bartoshuk et al., 2004). Ratings were scored in millimeters from the bottom of the scale. Samples were randomly served and coded with 3-digit random numbers; water and unsalted crackers were provided for palate cleansing between samples.

2.6. Data analyses

A two-way ANOVA test was conducted using 'NaCl content' and 'time' as factors to study the potential differences among fermentation conditions. Then, a one-way ANOVA test was conducted using 'NaCl content' as factor to study the final samples' differences. Tukey HSD was used as the post-hoc test. Differences among fermentation conditions or product samples were considered significant when $p < 0.05$, unless otherwise stated. All data analyses were conducted using the statistical package XLSTAT Version 2009.6.03 (Addinsoft, USA).

3. Results and discussion

3.1. Lactic acid fermentations characterization

Results of the fermentation process characterization showed significant differences ($p < 0.05$) among samples for both 'NaCl content' and 'time' factors, as well as for the interaction 'NaCl content*time'. The pH values sharply decreased from 4.6 ± 0.2 to 3.5 ± 0.1 in both 2% and 5% fermentation samples during the first 2 days, reaching the same final pH = 3.4 ± 0.1 at the end of the fermentation. In general, pH was slightly lower, and decreased faster in the 2% NaCl-content fermentation vessels at the beginning of the process. Food-safety conditions to ensure no growth of pathogen bacteria (pH < 4; Rahman and Rahman, 2020) were reached at day 1 in the 2% NaCl-content vessels, and at day 2 in the 5 %-NaCl vessels. These results were in concordance with a previous study in which *L. plantarum* was also used to ferment orange peels in a 5% NaCl brine and compared with a spontaneously driven process; pH values under 4 were reached after 12 h of fermentation (Deba-Rementeria et al., 2022).

Sucrose consumption was similar in both conditions, but lactic acid production was higher in the 2% NaCl-content fermentation vessels (Fig. 1). Some acetic acid was detected during the fermentation from day 4 until the end of the process; but the concentration was slightly higher in the 2% NaCl-content fermentation vessels. The maximum concentration of this acid was 0.3 g L^{-1} (day 6), significantly lower than the lactic acid one. These results suggested a higher microbial activity on the 2% NaCl-content fermentation vessels, probably because the 5% NaCl-content vessels were a more hostile environment for the *L. plantarum* development. Xiong et al. (2016) reported similar results for lactic acid bacteria, showing that the salt content had a significant effect on the pH reduction during the first 48 h of sauerkraut fermentation and that pH values decreased faster the lower the salt content was. Also, Yang et al. (2019) reported a greater lactic acid bacteria (LAB) activity when NaCl concentration was low, observing an inhibition of LAB growth during sauerkraut fermentation at concentrations of 2.5–3.5% NaCl. *L. plantarum* growth was not inhibited using a 5% NaCl concentration during the present research, but higher microbiological activity could be

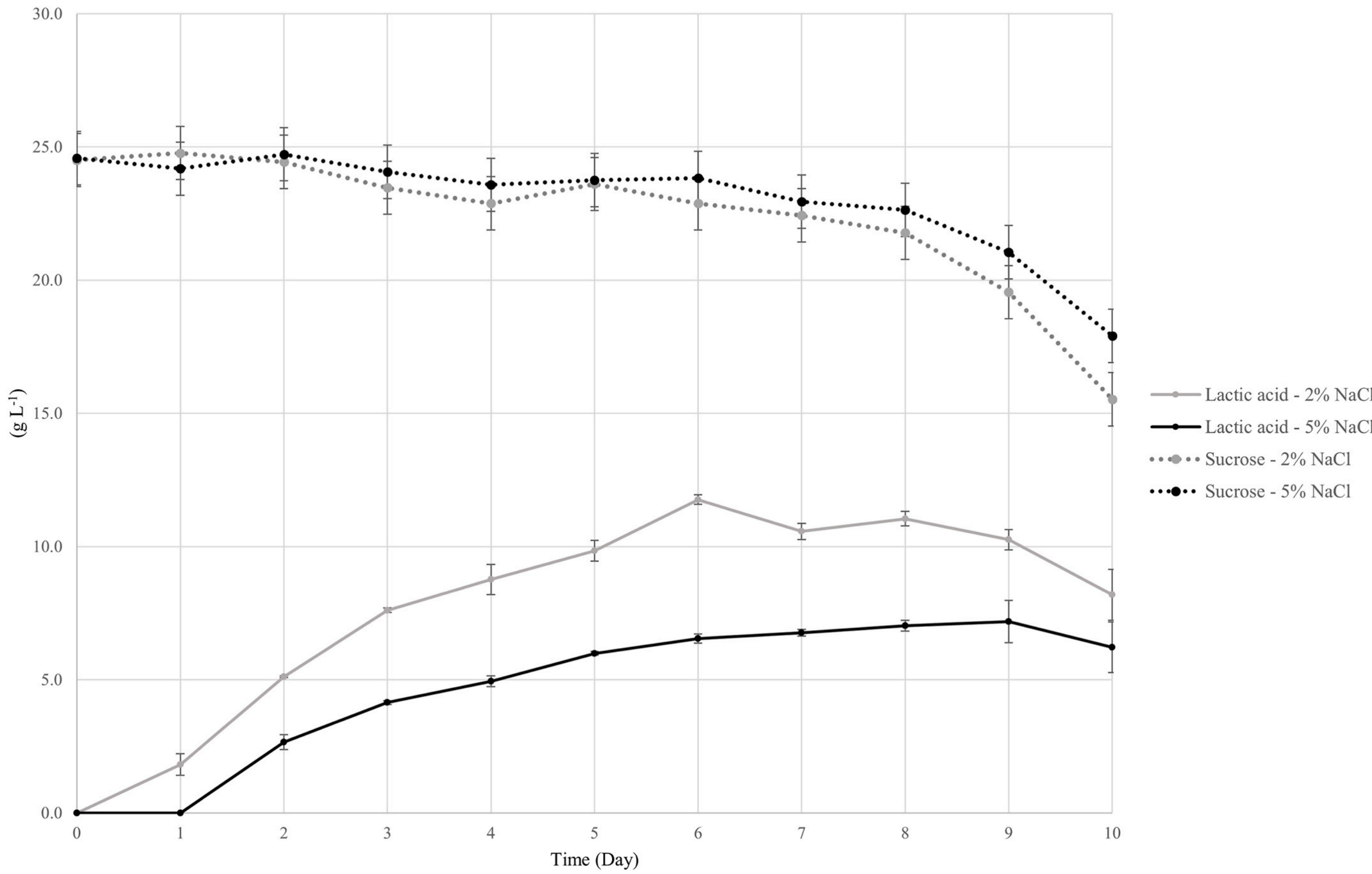

Fig. 1. Sucrose consumption and lactic acid generation during the orange peels fermentation.

observed when the NaCl concentration was lowered to a 2%.

3.2. Lactic acid fermented orange peels characterization

Table 1 shows the physico-chemical characteristics of blanched orange peel (OP) and lactic acid fermented peel (F) samples. In general, the main differences were detected between the composition of the OP and the F samples, being the 2% and 5 %-NaCl F samples quite similar between them. Ash content raised significatively from 3.71% in orange peel crude to 10.42% and 19.67% in the 2% and 5 %-NaCl F samples respectively, the increment was probably due to the salt added to the brines. Extractives, lignin, and carbohydrate concentrations were significatively lower ($p < 0.05$) in the F samples than in the OP, suggesting a metabolization of these compounds by bacteria during fermentation.

Instrumental color parameters were significantly different ($p < 0.05$) among the 3 studied products (Table 1). The 3 samples were significantly different in some parameters such as b* and Chroma; the 5%-NaCl F samples had a color closer to the OP than the 2%-NaCl F samples. ΔE*, calculated to determine the magnitude of the total color difference among samples after 10 days of fermentation, was significantly higher in the 2%-NaCl F samples than in the 5%-NaCl F samples, meaning a greater transformation of OP color in the process developed in the 2% NaCl brine. ΔE* has been reported to indicate significant differences between treated and untreated citrus juice samples when being over 0.5; differences are considered "great" when ΔE* is over 6.0 (Cserhalmi et al., 2006), as seen in the present research. These results suggested that the lower content in salt had the greater impact on the color of the fermented orange peels, which seemed to be more luminous (L*), having a higher color intensity (Chroma) and more yellowness (*b**), probably associated to a greater transformation of the peels because of a higher microbial activity during the process.

The results of the one-way ANOVA of the instrumental texture data (Table 1) showed significant differences between the OP and the F samples, being the two F samples similar between them and softer than the OP. Blanching has been reported as a process that softens orange peels (Deba-Rementeria et al., 2022). This previous research confirmed that the fermentation process conducted in orange peel samples without any pretreatment had a higher hardness than raw orange peels, similarly as previously reported by Deba-Rementeria et al. (2021). McMurtrie and Johanningsmeier (2018) showed that fermentation had a significative effect on cucumber texture and color. Cucumber mesocarp firmness was studied using a puncture test, and the fermented cucumbers had a higher firmness than the raw ones, similarly as reported by Deba-Rementeria et al. (2021). Therefore, in addition to fasten the process, depending on the later use of the product, blanching may be an interesting operation to tune the products' texture if a soft texture is desired.

The fermentation process was found to be significant on the total flavonoids content, being significantly lower in the F samples than in the OP sample. Total flavonoids decreased from 42 mg g^{-1} in the OP sample to concentrations below 20 mg g^{-1} in the F samples, which had a similar content between them. Flavonoids have received special attention in literature because several studies have reported potential benefits for human health associated to their consumption (Molina-Calle et al., 2015; Lachos-Perez et al., 2020). Raghuvanshi et al. (2019) explored the transformation of different fermented vegetables, measuring flavonoids concentration and their evolution during the fermentation process. These authors concluded that flavonoids evolution during a fermentation was matrix dependent; for example, flavonoids increased throughout the fermentation of peppers, while an overall decrease was detected during the fermentation of carrots. Also, flavonoids initially increased, and then decreased, during beets' fermentation, suggesting that the microbes driving the process may have been responsible of

Table 1
Results of the physico-chemical analyses of the blanched orange peel and the samples fermented by L. Plantarum in the 2% and 5% brines. Samples within the same row followed by different letters were significantly different; bold indicate the significant p-values.

	Orange peel (OP)	Fermented OP (2% NaCl)	Fermented OP (5% NaCl)	p-value
Moisture (%)	14.11 ± 0.32	14.82 ± 0.38	15.85 ± 1.55	0.313
Ashes (%)	3.71 ± 0.06 c	10.42 ± 0.26 b	19.67 ± 2.69 a	**0.005**
Extractives (%)	13.14 ± 0.08 a	5.80 ± 0.68 b	10.50 ± 0.93 a	**0.004**
Lignin (%)	16.70 ± 0.03 a	14.78 ± 0.42 b	14.39 ± 0.49 b	**0.016**
non-soluble	7.37 ± 0.22 b	9.62 ± 0.29 a	7.57 ± 0.03 b	**0.003**
soluble	9.33 ± 0.19 a	6.07 ± 0.15 b	6.83 ± 0.52 b	**0.005**
Carbohydrates (%)	46.74 ± 2.68 a	35.79 ± 0.52 b	37.46 ± 0.76 b	**0.013**
Glucan	25.96 ± 1.34 a	16.84 ± 0.14 b	18.63 ± 0.40 b	**0.003**
Xylan	15.60 ± 1.11 a	11.18 ± 0.66 b	11.68 ± 0.25 b	**0.019**
Araban	5.22 ± 0.23	5.78 ± 0.19	5.47 ± 1.25	0.766
Acetile	N.D. b	1.99 ± 0.19 a	1.67 ± 0.34 a	**0.006**
L*	56.22 ± 1.85 a	55.55 ± 3.09 a	51.66 ± 3.46 b	**0.001**
*a**	21.10 ± 3.81 a	13.58 ± 4.36 b	14.19 ± 2.43 b	**0.001**
*b**	48.29 ± 3.47 c	62.21 ± 4.86 a	56.45 ± 6.34 b	**0.001**
Chroma	52.88 ± 2.63 c	63.84 ± 4.45 a	58.27 ± 6.11 b	**0.001**
°Hue	66.32 ± 4.81 b	77.59 ± 4.31 a	75.76 ± 2.98 a	**0.001**
ΔE*		15.83 a	11.62 b	**0.001**
Firmness (g)	1405 ± 536 b	2592 ± 881 a	3250 ± 1280 a	**0.001**
Total flavonoids (mg hesperidin g^{-1})	41.55 ± 1.00 a	19.97 ± 1.36 b	19.61 ± 0.54 b	**0.001**

releasing the compounds from the plant, but also of their subsequent degradation. Results of the present study showed a significant reduction of total flavonoids during the lactic acid fermentation of orange peels by *L. plantarum*. Besides the associated health benefits, flavonoids have also been studied due to their relevance in contributing to the bitterness of different products (Goh et al., 2021). After the fermentation with *L. plantarum,* total flavonoids of orange peels significantly decreased to approximately a 50%, so it was expected that bitterness intensity would be perceived as lower as in the OP.

The results of the online survey conducted to study the expectations of the snack made with the fermented orange peels (n = 289, 52/48% of women/men respectively, mean = 42 ± 15 years old) are shown in Table 2. In general, respondents seemed to have a precise idea on the main reasons for using fermentation (e.g.: food preservation, flavor, and texture modification), and also the potential raw materials with which developing fermentative processes (e.g.: fruits, cereals, wine), probably associated to the main fermented foods consumed in the Spanish gastronomy (wine, beer, vinegars, yogurts). Besides marking the main microbial populations involved in fermentation, over 40% of respondents marked 'tradition', 'good for your health' and 'probiotic', showing a positive predisposition to fermented foods. Over 50% of respondents considered that milk, cereals, fruit peels, and wine were suitable raw materials for fermentation, and less than a 20% marked 'meat' or 'fish', indicating a potential unawareness that some of the most typical cured meat derivatives from Spain involve fermentation. Regarding the "*fermented and freeze-dried orange peel snack*", expectations showed a mean acceptance score of 5.5, with a 30% of respondents marking over 7 in the 9-points hedonic scale. Orange flavor, sour, fruity, orange color, crunchy, and bitter were the expected main attributes of the snack.

OP and F samples were assessed by a consumer panel (n = 61), rating liking on appearance, flavor, and texture, and saltiness and bitterness intensity perception in the gLMS. Results are shown in Table 3. Although appearance liking was significantly higher in the OP sample, texture and flavor liking was higher in the 2 %-NaCl F sample, being similar to the expected liking score (mean = 5.5). A 33% of respondents marked liking of the 2%-NaCl F sample over 7 points in the 9-points flavor hedonic scale, and a 39% marked liking of the 2%-NaCl F sample over 7 points in the 9-points texture hedonic being the potential consumer niche of this new product. Bitterness perception was significantly lower in the F samples than in the OP sample, being considered "moderate" in the F samples ("moderate" was the labeled category for the values between 33 and 68 mm) and "strong" in the OP sample ("strong" was the labeled category for the values between 68 and 102 mm). Saltiness perception was also different among samples, being considered "weak" in the OP sample and "moderate" in the F samples. Although saltiness was rated as significantly different between the F samples, its perception did not seem to have an impact on that of bitterness, which was similar between the F samples. It is possible that both the reduction on total flavonoids and the presence of salt and lactic acid had an impact on bitterness perception; results suggested that a 2%-NaCl content was enough to enhance liking and favor a lactic acid fermentation to transform the orange peels into a less-bitter ingredient. Different culinary practices such as sautéing, caramelizing, braising, or pickling have been listed as potential techniques to improve palatability and improve liking of foods by masking the bitterness of different vegetables (Drewnowski and Gomez-Carneros, 2000). During the present research, the combination of a traditional culinary practice to potentially reduce flavonoids content of the orange peels (lactic acid fermentation), as well as a sensory strategy to reduce bitterness perception (salt addition) were assessed, showing the feasibility of the whole process to develop a new product made from a by-product of oranges processing.

4. Conclusions

The results of the present study suggested that a *Lactiplantibacillus plantarum* driven fermentation in a 2% NaCl-brine could be a suitable method for debittering orange peels discarded from orange juice making, as well as to enhance consumer acceptance when presented as a

Table 2
Check-All-That-Apply responses of the consumer' survey conducted to determine expectations of the new snack. Legend: only the terms marked by over 40% respondents have been listed in the table.

Terms associated to 'fermented'		Potential raw materials for fermentation		Reasons for using fermentation		Expected sensory properties of the *freeze-dried orange peel snack*	
Traditional	40%	Whole fruits	44%	To develop aromas	48%	Crunchy	45%
Good for your health	42%	Cider	46%	To change the flavor	49%	Bitter	45%
Mold	46%	Wine	51%	To change the texture	52%	Orange color	48%
Probiotic	52%	Fruit peels	52%	As a probiotic	56%	Fruity	50%
Bacteria	72%	Cereals	71%	To produce alcohol	62%	Sour	52%
Yeast	76%	Milk	73%	To preserve foods	73%	Orange flavor	76%

Table 3
Results of the consumer study: acceptance of appearance, flavor, and texture in a 9-point hedonic scale, and saltiness and bitterness intensity perception in a gLMS (mm). Samples within the same column followed by different letters were significantly different; bold to indicate the significant p-values.

	Appearance acceptance	Flavor acceptance	Texture acceptance	Bitterness intensity	Saltiness intensity
OP sample	5.90 a	4.34 b	4.78 b	75.5 a	14.2 c
2%-NaCl F sample	5.70 ab	5.48 a	5.82 a	39.1 b	38.3 b
5%-NaCl F sample	5.08 b	5.13 ab	5.53 ab	34.7 b	51.5 a
p-value	**0.020**	**0.004**	**0.015**	**<0.0001**	**<0.0001**

freeze-dried snack. The 2% NaCl-condition led to a higher microbial activity and higher lactic acid production during the process, obtaining pH values lower than 4 at 24 h after starting the fermentation. Significative differences were detected among samples in their physico-chemical properties, and total flavonoids content was significatively reduced during fermentation. The consumer study showed that the expectations identified during the initial consumer survey were met, and that a snack made with the fermented samples was more liked, and perceived as less bitter, than a snack made with the non-fermented orange peel. To replicate the pickled-lemons North-African culinary tradition, but inducing a lactic acid fermentation, was useful to transform a Mediterranean by-product into a new successful ingredient. Further studies should be carried out to propose new dishes of Spanish gastronomy that include the new ingredient, promoting the upcycling of orange peels in situ in one of the main places of production: hotels and restaurants.

Data availability

Data will be made available on request.

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