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Effects of sodium substitution with potassium in brines for packing natural black olives of the criolla cultivar

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SUMMARY: The high global sodium consumption presents a significant challenge to public health. In response to this issue, the olive industry has been trying to use substitutes with lower sodium content for the production of table olives. Therefore, the objective of this study was to evaluate the effect of five mixtures of NaCl and KCl salts (40/60, 30/70, 70/30, 50/50, and 60/40 respectively), compared to a reference treatment containing only NaCl, and to analyze both sensory perception and physicochemical and microbiological parameters. The results did not reveal any statistically significant differences in sensory profiles (p-value = 0.4226), indicating that the partial substitution of NaCl with KCl does not negatively affect the sensory attributes of olives. These findings were supported by physicochemical and microbiological analyses that met the parameters and standards established by current regulations. Therefore, potassium chloride could be a viable substitute for sodium content reduction without compromising the quality and preservation of the product.

KEYWORDS: *Black olives; Potassium chloride; Salt mixture; Sensory perceptions.*

RESUMEN: ***Efectos de la sustitución de sodio por potasio en salmueras de envasado de aceitunas negras naturales del cultivar Criolla.*** El elevado consumo global de sodio en la alimentación representa un importante desafío para la salud pública. En respuesta a esta problemática, la industria del olivar busca estrategias para utilizar sustitutos con menor contenido de sodio en la producción de aceitunas de mesa. Por lo tanto, el objetivo del estudio fue evaluar el efecto del uso de cinco mezclas de sales NaCl y KCl (40/60, 30/70, 70/30, 50/50, 60/40, respectivamente), en comparación con un tratamiento de referencia que contenía únicamente en NaCl, analizando tanto la percepción sensorial como los parámetros fisicoquímicos y microbiológicos. Los resultados no revelaron diferencias estadísticamente significativas en el perfil sensorial (valor p = 0,4226), lo que indica que la sustitución parcial de NaCl por KCl no afecta negativamente a los atributos sensoriales de las aceitunas. Estos hallazgos se respaldan con análisis fisicoquímicos y microbiológicos que cumplen con los parámetros y estándares establecidos por la normativa vigente. Por lo tanto, el cloruro de potasio podría ser un sustituto viable para reducir el contenido de sodio sin comprometer la calidad y la conservación del producto.

PALABRAS CLAVE: *Aceituna negras; Cloruro de potasio; Mezcla de sales; Percepciones sensoriales.*

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1. INTRODUCTION

The olive tree, scientifically known as *Olea europaea* L., is one of the oldest fruit-bearing trees. It originates from the eastern Mediterranean coast, extending to present-day regions such as Turkey, Lebanon, and Israel. For thousands of years, the olive has been extensively cultivated, primarily for the production of olive oil and table olives (Sales *et al*., 2021). Over time, its cultivation has spread throughout the Mediterranean basin, with Spain, Egypt, and Turkey currently ranked as the leading worldwide producers (International Olive Council, 2022; Julca *et al*., 2020). Due to a growing demand for olive oil and table olives, its cultivation has expanded to several countries such as Australia, China, the United States, and several Latin American countries (Torres *et al*., 2017).

As for table olives, they represent a fermented food product of great nutritional value and play a prominent role in the economy of many countries (Anagnostopoulos and Tsaltas, 2022; Conte *et al*., 2020). These olives are divided into three categories according to the degree of ripeness of the raw fruit: green olives, turning-color olives, and black olives (Rejano *et al*., 2010). Traditionally, sodium chloride (NaCl) is the main component of the brine used in table olive processing to ensuring physicochemical, microbiological, and sensory properties (Degirmencioglu, 2016). Specifically, NaCl controls microbial activity by inhibiting spoilage microorganisms and promoting the growth of beneficial lactic acid bacteria, stabilizes pH and regulates water activity, contributing to texture and firmness. In addition, NaCl enhances the sensory profile by balancing acidity and bitterness; while its role in storage and packaging extends product shelf-life by maintaining microbial stability and organoleptic quality, making its use essential for preserving the final product (Pires-Cabral *et al*., 2018).

However, the sodium levels present in table olives have raised increasing concerns among consumers (Rocha *et al*., 2020) due to its association with chronic diseases such as hypertension and cardiovascular problems (Wang *et al*., 2020). Consequently, reducing the sodium content in processed olives is one of the goals of table olive producers.

Several studies have partially substituted NaCl with potassium chloride (KCl) in the brine during the fermentation phase (Bautista-Gallego *et al*., 2011; Pino *et al*., 2018). However, few studies have addressed this substitution in the final packaging of olives (López-López *et al*., 2023).

The objective of this study was to understand the sensory, physicochemical, and microbiological effects of different partial sodium-to-potassium substitutions in the packaging of natural black olives of the Criolla cultivar, as a first step towards the commercialization of healthier olives.

2. MATERIALS AND METHODS

2.1. Experimental design

The olives used in the experiment were of the Criolla cultivar, fermented as natural black olives with an average size of 165±15 units/kg. The fermentation process was carried out in an initial brine of 8° Baumé, which was maintained throughout the fermentation period of 120 days. The process was considered complete when free acidity reached a value equal to or greater than 1.5%, expressed as lactic acid. After fermentation, the olives were classified and selected by size and stored in polyester resin tanks reinforced with fiberglass, with a capacity of 2500 kg. The olives were preserved in the filtered fermentation brine. The size range used for the experiment was 150–180 units/kg, with all samples coming from the same storage tank, corresponding to a single harvest and processing batch.

For packaging, the brine consisted of a mixture of sodium chloride (NaCl) and potassium chloride (KCl) solutions, both at a concentration of 6° Baumé. Five experimental treatments (A-E) were prepared with different NaCl/KCl mixture proportions (%): A (40/60), B (30/70), C (70/30), D (50/50), and E (60/40). A reference treatment (F) containing 100% NaCl was also included for comparison.

The prepared brines were pasteurized at 90 °C for 10 minutes to eliminate microbial load. The brine was then cooled to a temperature of 25-28 °C for approximately 2 hours, after which 0.5 g/L of commercial potassium sorbate ($C_6H_7KO_2$) was added as a preservative. While still at 90 °C, the brine was added to the olives during packing to ensure that the final product temperature reached approximately 65 °C, which contributed to microbial stability. The olives were packed in multi-layer pillow bags (Swich Pack, Peru), each containing 500 g of olives and 300 ml of brine. After sealing, the packs were stored at room temperature in the dark.

The evaluation period was limited to 6 months, reflecting the typical rotation cycle for this type of product in commercial distribution. Although the brine was not acidified, the free acidity of the olive juice, measured at 1.6% (expressed as lactic acid), combined with the addition of potassium sorbate at a concentration of 0.5 g/L, provided additional chemical stability to the product. After 6 months' storage, sensory, physicochemical and microbiological evaluations were carried out to assess the quality and stability of the product.

2.2. Physicochemical and microbiological analyses

The pH and free acidity of the packaging brine were determined following the method described by

Fernández *et al*. (1997); while the chloride content in the salts (NaCl/KCl) was measured using a Boeco hydrometer (Germany) on a scale of 0 to 10° Baumé and divisions of 0.1. The microbiological evaluation included counting the yeasts and molds using the plate inoculation method by spread plating, following AOAC 997.02, 21st Edition, 2019. Four dilutions were performed in duplicate in a peptone water solution, ranging from 10^2 to 10^5. For the colony-forming unit (CFU) count, plates containing between 20 and 200 colonies were selected. The final result was calculated as the average of three samples using 3M™ Petrifilm plates.

The sodium content in the initial sample was measured by flame spectrophotometry according to AOAC 984.27-1986 in an accredited laboratory. At the end of the evaluation, the sample from the treatment with the highest acceptance was selected. Statistical differences were analyzed using ANOVA in RStudio software.

2.3. Sensory evaluation

A sensory evaluation was carried out according to the Tasting Standards for Table Olives of the International Olive Council (2021). A panel of 10 experts, trained according to the methodology of González *et al*. (2007) performed the evaluation. A quantitative descriptive analysis (QDA) approach was used, using an unstructured linear scale to describe the intensity of product attributes. This scale allowed precise measurements of the distance from the starting point to the judges' mark, providing robust and reproducible results.

The sensory evaluation included the analysis of negative attributes (abnormal fermentation, mold, cooked), flavor attributes (salty, bitter, and acidic), and kinesthetic attributes (hardness, fibrousness, and crispness). A comparative evaluation test was performed to identify differences among the samples and the reference treatment. The coefficient of robust variation was calculated using Microsoft Excel, with attributes considered acceptable if the coefficient was 20% or less.

Statistical analyses were performed to ensure the reliability of the sensory evaluation. Analysis of variance (ANOVA) and multiple range tests were applied using RStudio software to determine significant differences among treatments. These analyses facilitated the identification of the treatment with the highest sensory acceptability, ensuring that the results were both statistically valid and relevant to practical application.

2.4. Statistical analysis

The sensory analysis data were processed using a Microsoft Excel program developed by the International Olive Council (IOC) to calculate the robust coefficient of variation. Attributes were considered acceptable if the coefficient was equal to or less than 20%, as required by IOC standards. Comparative analyses among the samples and the reference treatment were performed using analysis of variance (ANOVA) and multiple range tests with RStudio software.

3. RESULTS AND DISCUSSION

3.1. Physicochemical and microbiological evaluation

Table 1 shows that the pH of the treatments ranged from 2.9 to 3.1 units, values below the maximum limit of 4.3 as established by the International Olive Council (2004) to ensure the safety of table olives. Under these conditions, the environment does not favor the development of pathogenic bacteria (Medina *et al*., 2013).

On the other hand, the free acidity in the brine, expressed as a percentage of lactic acid, ranged from 1.1 (B) to 1.2% (E) for the six treatments (A-F). These values are similar to those reported by Lanza

Table 1. Physicochemical and microbiological parameter results after packaging for 180 days

Treatment	pH	Free Acidity (%)	Salt Concentration (°Baumé)	Yeasts (UFC/mL)
A	2.9	1.12	7	< 10
B	3.1	1.1	7	7.1×10^2
C	2.9	1.18	7.1	2.1×10^2
D	3	1.18	7	1.6×10^2
E	3.1	1.2	7	3.5×10^2
F	3.1	1.18	7	5.6×10^3

Note. A: 40% NaCl and 60% KCl; B: 30% NaCl and 70% KCl; C: 70% NaCl and 30% KCl; D: 50% NaCl and 50% KCl; E: 60% NaCl and 40% KCl; F: Reference brine 100% NaCl.

et al. (2013) and lower than those reported by Clavijo *et al.* (2013) for the same cultivar and preparation. The acidity came from the olives because the brine had not been acidified, and the acidity equilibrated between the olives and the brine over time. No significant differences (p-value > 0.05) were found among treatments when evaluated by ANOVA using RStudio software.

The salt concentration in all treatments was very similar at between 7° and 7.1° Baumé, and as in the previous cases, no statistically significant differences were observed at the end of the packaging period. This concentration was adjusted to compensate for the high expected free acidity and to reduce the sensation of acidic taste, which was achieved mainly in treatments C and D and to a lesser extent in treatment A (Table 2).

Regarding mold and yeast counts, the data indicated that the amount of mold in all treatments was less than 10 CFU/mL; whereas the yeast count ranged between < 10 CFU/mL and 5.6x10^3 CFU/mL. Except for treatment F, all brines complied with RM 591-2008/SA item XIV.3 of the Ministry of Health of Peru (2008), which establishes that yeast counts must be less than 10^3 CFU/mL as a microbiological quality and food safety criterion. In a similar study, Bautista-Gallego *et al*. (2018) reported similar yeast counts when zinc chloride ($ZnCl_2$) was used as an antifungal agent instead of potassium sorbate. These results suggest that salt mixtures supplemented with potassium sorbate may have slightly better antifungal activity than pure solutions of NaCl.

3.2. Sensory evaluation

Sensory properties are key to determining the quality of table olives (Lanza *et al*., 2013). Therefore, negative, gustatory, and kinesthetic attributes were evaluated.

Table 2 shows the sensory analysis data, expressed as averages of the different attributes evaluated. The central value of the evaluation scale was 5 points, which represents the midpoint of the unstructured linear scale used in the study. The mean of the Defect Predominantly Perceived (DPP), including abnormal fermentation, was less than 3 points in all treatments. According to the analysis method of the International Olive Council (2021), the olives are classified as extra quality.

The overall assessment of the treatments showed that the average scores ranged between 3.20 ± 1.99 and 3.70 ± 2.32 points. Excluding defects, the range was adjusted between 4.00 ± 1.75 and 4.60 ± 1.99 points, approaching the average score. The comparison of mean scores for each treatment did not reveal significant differences (p-value = 0.8866), which is consistent with the ranges reported by Bautista-Gallego *et al.* (2018). From an applied sensory perspective, these scores, which range from 3 to 7 points, correspond to moderate sensory intensities, indicating that the formulations evaluated are neither too low nor too high. This suggests that the treatments are sensory acceptable and in line with the medium sensory range reported in comparable studies.

Table 2. Scores of formulations with different salt concentrations ($\overline{X}$ ± SD)

Mixtures	A	B	C	D	E	F
Abnormal Fermentation	1.10 ± 0.32	1.10 ± 0.32	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
Other Defects	1.00 ± 0.00	1.10 ± 0.32	1.00 ± 0.00	1.10 ± 0.32	1.00 ± 0.00	1.00 ± 0.00
Salty	5.30 ± 1.33	4.60 ± 1.37	4.90 ± 1.09	5.30 ± 1.28	5.20 ± 1.52	6.20 ± 1.38
Bitter	4.20 ± 1.69	3.70 ± 1.68	3.50 ± 1.66	3.70 ± 2.20	3.30 ± 1.40	3.40 ± 1.13
Acid	5.10 ± 1.63	5.80 ± 1.30	4.80 ± 2.51	5.70 ± 1.97	5.80 ± 2.11	5.90 ± 1.77
Hardness	3.70 ± 1.85	3.90 ± 1.40	3.80 ± 1.44	4.10 ± 1.60	4.90 ± 1.96	3.70 ± 1.13
Fibrousness	3.90 ± 2.13	3.50 ± 1.24	3.10 ± 1.82	3.40 ± 1.53	4.10 ±1.95	3.40 ± 1.66
Crunchiness	3.30 ± 1.27	4.20 ± 1.68	3.60 ± 1.20	3.90 ± 1.71	4.20 ± 2.26	3.80 ± 1.77
Final Rating	3.50 ± 2.07	3.50 ± 1.96	3.20 ± 1.99	3.50 ± 2.17	3.70 ± 2.32	3.60 ± 2.18
Final Rating without Defects	4.30 ± 1.77	4.30 ± 1.59	4.00 ± 1.75	4.40 ± 1.87	4.60 ± 1.99	4.40 ± 1.85

Note. Results are presented as mean ($\overline{X}$) ± standard deviation (SD) of three replicates. No significant differences were found at the p < 0.05 level as assessed by Duncan's multiple range test. A: 40% NaCl and 60% KCl; B: 30% NaCl and 70% KCl; C: 70% NaCl and 30% KCl; D: 50% NaCl and 50% KCl; E: 60% NaCl and 40% KCl; F: Reference brine 100% NaCl.

In the analysis of the salty sensation, no significant differences (p-value > 0.05) were observed among the sample means. These results are similar to those reported by Lanza and Amoruso (2016) and higher in value than 3.8 for packaged natural olives (Bautista-Gallego *et al*., 2018). However, the treatment with 100% sodium chloride, resulted in a stronger salty sensation, although there it was not statistically different from the others. Treatments B and C, showed values close to 4.9, as similar to the results of other studies (Bautista-Gallego *et al*., 2018). Treatments A and D showed values comparable to those reported for the Italian cultivar (Lanza and Amoruso, 2016).

The variation in salt concentration did not seem to have a significant effect on these perceptions, which was confirmed by a robust coefficient of variations equal to zero. Regarding the salty attribute, formulations C, D, and E showed a progressive increase, indicating a positive trend toward salt concentration, similar to the reference sample (F). Thus, a minimum reduction of 25.70% in NaCl could be achieved, as observed in treatment C, as reported in the study by Moreno-Baquero *et al.* (2013). A 50% reduction is also feasible, as found in treatment D, supported by the results for bitterness and acidity attributes, which were comparable to those of the reference sample (F).

Regarding the bitter taste, no significant differences were found (p-value = > 0.05), with the 100% sodium chloride treatment showing the highest value, comparable to the results obtained with zinc chloride (Bautista-Gallego *et al*., 2018). The measured values remained below 5 points. In this regard, some authors, such as Conte *et al.* (2020), pointed out that olives with high levels of bitterness are considered unmarketable.

The analysis of the acidic flavor also showed no significant differences (p-value > 0.05). The mean values by treatment ranged from 4.80 ± 2.51 to 5.80 ± 2.11, in line with the values reported for the Oliva di Gaeta and Oliva Bianca varieties (Lanza and Amoruso, 2016). In sensory evaluation, excessively acidic flavors are typically associated with values close to the upper end of the scale, which in this case is 10. According to Randazzo *et al*. (2018), values greater than 7 are considered high and can have a negative impact on marketability. Excessively acidic flavors may also impact marketability (Conte *et al*., 2020).

For the kinesthetic attributes, no significant differences were found among treatments; hardness (p-value > 0.05) was homogeneously grouped with means between 3.70 ± 1.85 and 4.90 ± 1.96. These results are similar to those reported for the Oliva di Gaeta variety (Lanza and Amoruso, 2016), slightly lower than those of the Chalkidiki variety (7.0 ± 1.5), and higher than the values obtained for zinc chloride (Bautista-Gallego *et al*., 2018).

In terms of fibrousness, the values ranged from 3.10 ± 1.82 to 4.10 ± 1.95, with no significant differences (p-value > 0.05), and the treatments were homogeneously grouped. These values were slightly lower than those reported by Lanza and Amoruso (2016) but similar to those reported by Bautista-Gallego *et al*. (2018). Crunchiness also showed no significant differences (p-value = 0.8866), fluctuating in a mean range from 3.30 ± 1.27 to 4.20 ± 2.26, with treatments B and E scoring the highest values compared to those reported by Bautista-Gallego *et al*. (2018).

The overall acceptability of table olives with the addition of potassium chloride was similar across all samples (p-value > 0.05), with no significant differences compared to the reference sample. This finding supports the idea that sodium substitutes, such as potassium chloride, can reduce sodium intake in foods without compromising consumer acceptance. Similar results have been reported in studies on table olives and other food matrices where sodium chloride was substituted by potassium chloride (Bautista-Gallego *et al*., 2011; Bautista-Gallego *et al*., 2018; Lanza and Amoruso, 2016; Moreno-Baquero *et al*., 2013). Specifically, studies with pickled tomatoes, aloe vera, and lemon highlighted the sensory acceptability of these substitutes (Bansal and Rani, 2014; Mocanu *et al*., 2022). These findings reinforce the viability of using sodium substitutes, such as potassium chloride, to reduce sodium intake without compromising product quality, as evidenced by the physicochemical, microbiological, and sensory results.

By conducting an analysis of the robust variability coefficient (CVr), as shown in Table 3, a distinctive pattern in the results for various taste and kinesthetic perceptions was revealed. Regarding taste perceptions, sample B exhibited the highest relative variability (16.46%) in the salty attribute, whereas sample C showed the most notable variabilities in the bitter (23.65%) and acidic (25.45%) attributes, thus exceeding the 20% threshold established by the

Table 3. Coefficient of Variation (CVr %)

Formulations	Taste Perceptions			Kinesthetic Perceptions		
	Salty	Bitter	Acid	Hardness	Fibrousness	Crunchiness
A	7.71	10.88	9.90	16.79	43.92	9.32
B	16.46	5.39	11.15	13.72	6.83	19.72
C	9.55	23.65	25.45	18.54	94.67	9.15
D	5.71	14.50	8.19	9.25	13.66	4.98
E	9.38	12.20	14.19	12.55	16.19	19.74
F*	5.86	9.30	12.42	11.88	9.47	6.97

Note. The CVr % data for negative perceptions, whether for abnormal fermentation or other conditions, were set to 0 in all formulations. *Sample F represents the reference treatment.

International Olive Council (COI). In the realm of kinesthetic perception, sample C stood out with the highest relative variability for the hardness attribute (18.54%) and, significantly, in fibrousness (94.67%) compared to the other samples. Given the high variability observed in Sample C, particularly in bitterness, acidity, and fibrousness, this brine formulation may not be suitable for consumer preference. Such high variability indicated that the product may be inconsistent, which could negatively impact its marketability and consumer acceptance.

The variability of the results was greater for the preparation of natural black olives compared to treated green olives, which is attributed to variety and its technological characteristics (Panagou *et al*., 2006). On the other hand, for the crunchiness attribute, sample E showed the highest variability (19.74%). The reference sample (F) was characterized by relatively low coefficients of variation compared to the other samples. It is important to note that the CVr for negative perceptions (abnormal fermentation or others) was consistently equal to 0 across all formulations, indicating an absence of variability in these perceptions among the samples.

3.3. Multivariate analysis by sensory attributes

In Figure 1, the main dimensions are presented, where "Dim 1 (43.71%)" and "Dim 2 (22.86%)" together explain 66.57% of the variability in the results. This indicates that these two dimensions capture most of the information regarding the evaluated sensory perceptions.

In Figure 1m, the treatments are grouped according to the two dimensions of Principal Component Analysis (PCA). Treatments A and B are placed at the top of the graph and form a distinct group, while treatments D and E are closely grouped with similar KCl contents ranging from 40 to 50%. At the bottom of the graph, treatments C and F form another cluster with lower KCl contents (30 and 0%, respectively). These groupings reflect patterns in the data,

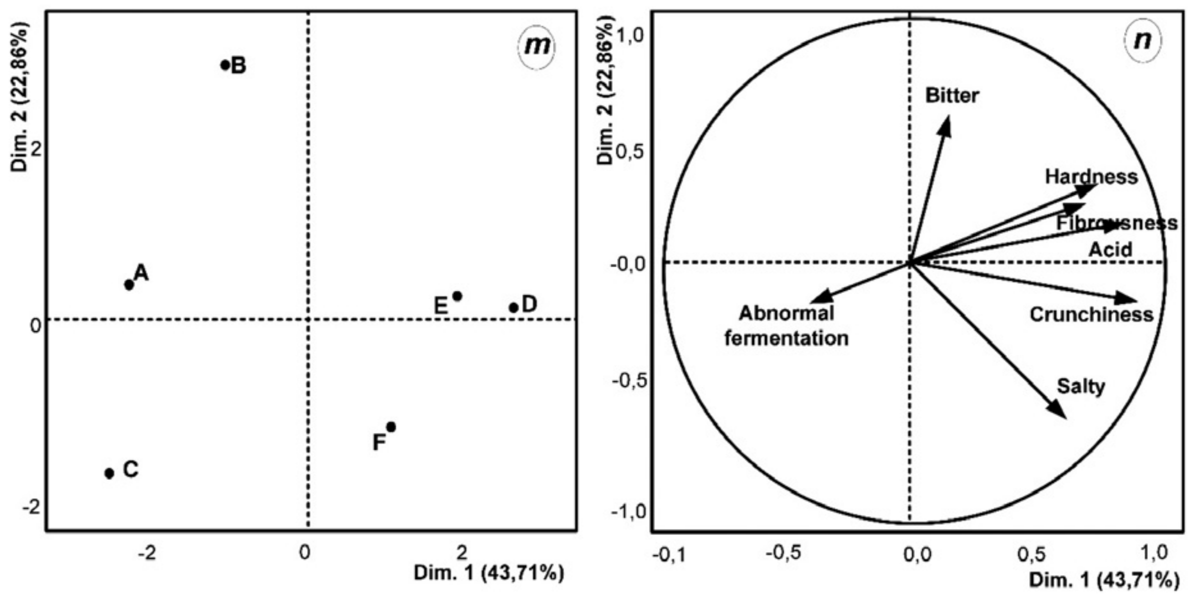

Figure 1. Projection of sensory attributes.
Note. Principal component plot, *m* = scatter plot, *n* = correlation circle.

but do not imply significant differences in sensory attributes or acceptability, since no significant differences were observed in Table 1. Therefore, the PCA shows how the treatments are distributed according to the dimensions evaluated, but does not determine the specific factors that influence positive or negative sensory perceptions.

Dim. 1 component seems to capture variations in the salt composition of the different treatments, as shown by the clear clustering of formulations with different NaCl and KCl ratios. Treatments with more balanced salt mixtures, such as D and E, are positively positioned along this dimension. In contrast, treatments with predominant concentrations of one salt or lack of balance are distributed differently, which may indicate that Dim. 1 reflects variability in formulation strategies rather than a direct sensory relationship.

In the correlation circle (Figure 1*n*), there was a high and positive correlation between hardness and fibrousness. This suggests that the perception of fibrousness increased as the hardness of olives increased, which could be beneficial for the texture of this product. These variables also show a positive correlation with the acidic and crunchiness attributes, although the group exhibits a null or minimal correlation with the bitter and salty attributes. This indicates that the perceptions of hardness and fibrousness may be more related to positive than negative sensory attributes.

Additionally, the variables of hardness, fibrousness, acidity, and crunchiness showed a high but negative correlation with abnormal fermentation, suggesting that the perception of these sensory attributes was favorable, while abnormal fermentation had a negative impact on overall sensory acceptance. Samples D and E, characterized by being crunchier, more acidic, fibrous and harder, had a more positive perception. In contrast, sample A was associated with a higher perception of abnormal fermentation, although it was less acidic and crunchy.

Finally, reference sample (F) presented a lower bitter sensation, indicating that despite not containing KCl, it was still positively valued. On the other hand, sample C, which exhibited lower hardness and fibrousness, also showed a greater perception of abnormal fermentation. However, it is noteworthy that the olives were still classified as extra-quality, highlighting their acceptance in the market.

On the other hand, Figure 2 shows significant patterns in the evaluation of sensory attributes. The lower variability in abnormal fermentation suggests a possible consensus among the judges regarding this attribute, indicating that perceptions are more homogeneous.

However, the presence of outliers and the lack of uniformity in the “other” category could complicate coherent acceptance, suggesting that some judges had differing opinions on these aspects. Additionally, a uniform distribution in the salty attribute indicates a consistent evaluation; the high ratings for the acidic and hardness attributes suggest that the judges perceived these characteristics as positive, while the lower ratings for fibrousness and crunchiness indicate a lesser appreciation for these attributes.

3.4. Reduction in sodium content in olive pulp

Considering that no significant differences were found in sodium content among the different analyzed samples, sample B exhibited a lower proportion of NaCl, resulting in a sodium content of 1210.70 ± 10 mg/100 g of olives. In contrast, reference sample F had a value of 1632.10 ± 10.10 mg/100 g of olives, representing a 25.7% reduction in sodium content compared to the latter.

These results are slightly lower than those obtained by Saúde *et al*. (2017), who reported sodium values of 2510 ± 30 mg and 2040 ± 70 mg, respectively, with a 19% reduction when using salt mixtures in the fermentation of crushed olives in a

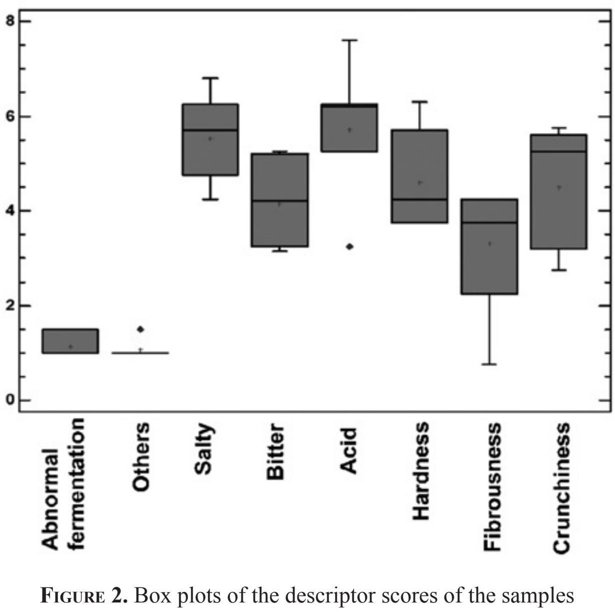

Figure 2. Box plots of the descriptor scores of the samples

ratio of 50% NaCl and KCl. This finding does not meet the sodium intake recommendations.

Table 4 shows the results for the sodium content in olive pulp by treatment. The initial sodium content in olives before packing was 1774.47 mg/100 g. When packed in a covering medium with a lower salt concentration (6º Baumé), the sodium concentration in the pulp decreased by diffusion. At equilibrium, the sodium concentration in the pulp was reduced to 1632.10 ± 10.10 mg/100 g for the treatment with brine containing only sodium chloride, with the lowest value observed being 1210.70 ± 10.00 mg/100 g in sample B. This represents a 25.7% reduction in pulp sodium compared to sample F and a 31.7% reduction compared to the initial values.

The sodium reduction achieved in sample B is significant. Although the analysis was standardized using a 100 g serving as reference, which corresponds to a sodium intake of 1210.70 ± 10.00 mg (approximately 60% of the daily sodium recommendation for adults), it is important to note that the typical consumption of olives ranges from 4 to 7 units per day, corresponding to 15-25 g. Considering this habitual intake, the sodium contribution of sample B would be between 181.52 and 302.53 mg/day, representing 12.1-20.2% of the daily sodium intake recommended by the American Heart Association (1500 mg/day). These results highlight the significant sodium reduction achieved in Sample B, taking into account realistic olive consumption patterns.

4. CONCLUSIONS

The research demonstrates that the partial substitution of sodium chloride with potassium chloride in the brines used to packaging table olives can be a positive strategy to obtain a healthier product due to the reduction of sodium. This substitution is considered favorable in all tested treatments because it does not negatively affect the sensory attributes of the olives. Since no significant differences were found among the treatments, treatment B was chosen, which has the lowest sodium chloride content, and achieved a 25.7% reduction in sodium content.

Moreover, physicochemical analyses indicated that the parameters of pH, free acidity, and chloride content remained stable over 180 days, complying with packaging standards for natural black olives. The microbiological analyses also met the quality criteria established by national regulations.

The results of this study highlight the importance of continuing to investigate techniques for replacing sodium with potassium in the packaging of olives. It is necessary to explore alternative salt substitution methods that can be applied before packaging. This line of research could facilitate the production of healthier olives while maintaining traditional organoleptic quality.

Table 4. Sodium values in olive pulp ($\overline{X}$ ± SD)

Formulations	Sodium chloride proportion (%)	Sodium in Pulp (mg/kg)
A	40	1289.40 ± 9.90
B	30	1210.70 ± 10.00
C	70	1532.80 ± 10.60
D	50	1372.50 ± 7.10
E	60	1453.90 ± 8.40
F	100	1632.10 ± 10.10

The results are presented as the mean ($\overline{X}$) ± standard deviation (SD) of the three replicates.

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DECLARATION OF COMPETING INTEREST

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AUTHORSHIP CONTRIBUTION STATEMENT

Y. Chata: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Data curation. **A. Mamani:** Conceptualization, Investigation, Writing – original draft, Data curation. **M. Gallegos-Arata:** Conceptualization, Formal analysis, Methodology, Writing, Resources, Validation, Writing – original draft. **R. Cartagena-Cutipa:** Formal Analysis, Methodology, Software, Validation, Visualization, Writing – review & editing.

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