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The Effect of Calcium in the Fermentation of White Cabbage with Salicornia

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Abstract: This study investigates the fermentation of white cabbage with salicornia and $CaCl_2$ to assess its effect on the fermentation profiles and properties of the final products. Two sets of experiments were performed: A—cabbage with salt and salicornia, and B—cabbage with salt, salicornia, and $CaCl_2$. The fermentative processes were studied through the microbial (lactic-acid bacteria (LAB), coliforms, and fungi), physicochemical (pH, total acidity), and mineral properties. A diminution of pH values (4.07, 3.58) and increased acidity values (0.70, 0.77 g lactic acid/100 mL) were registered at the end of the fermentation period (A and B, respectively). A stationary phase followed the exponential growth of LAB, and a slight decrease was observed (6.01, 5.51 Log CFU/g) in both experiments. A fungi decline was observed during the first week and the coliform populations disappeared after about 13 days of fermentation. *Staphylococcus* coagulase-positive, *Escherichia coli*, and *Salmonella* were not detected in the final products. The utilization of $CaCl_2$ resulted in fermented cabbage with analogous microbial and sensorial characteristics to fermented cabbage without $CaCl_2$ but with an increased hardness. However, Ca interfered with the diffusion of K, Mg, and Zn, resulting in lower levels of these elements in the final product, particularly Zn, which exhibited a reduction of 37%, reducing the nutritional value of the final products.

Keywords: *Brassica oleracea*; salicornia; calcium chloride; fermentation; physicochemical properties; microbiological characteristics; mineral composition

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1. Introduction

Fermented foods and beverages are "made through desired or microbial growth and enzymatic conversion of food components" [1]. The interest in this group of foods has increased with the rising demand for novel flavors, textures, and appealing nutritional properties. Some fermented foods may possess functional attributes, including prebiotic, probiotic, and postbiotic characteristics that emerge during the production process in addition to their preservation properties [1,2]. In addition, fermentation represents an economically viable and energy-efficient method of enhancing the value of plant materials and reducing waste, thereby contributing to the food system's sustainability. It is possible to conduct successful fermentations using raw materials that do not meet the conventional

standards for quality and value, as well as those derived from the food industry (by-products), as emphasized in recent studies [2–4].

Sauerkraut (fermented white cabbage), one of the most popular fermented foods, is widely consumed in northern European countries, some Asian countries, and the United States [5,6]. Sauerkraut is produced using white cabbage, a member of the Brassicaceae family of the species *Brassica oleracea* (var. capitata). Investigations have been conducted into the antioxidant, anticarcinogenic, and other health-promoting properties of these vegetables, which can be attributed in part to their contents of organosulfur compounds and phytochemicals [7–10]. Their content of the amino acid S-methylmethionine is associated with reduced formation of stomach tumors [11], prevents the adhesion of pathogens to the intestinal mucosa, and confers immunostimulant or hypocolestrogenic activity [3,12]. The fermentation of cabbage by lactic-acid bacteria (LAB) can produce fermented cabbage with high glucosinolate retention, high levels of free phenolic compounds, and total flavonoid content [13]. In addition, Pires-Cabral (2022) [14] reported higher values of antioxidant activity of fermented cabbage compared to the raw materials. A clinical study investigating the health benefits of sauerkraut [15] involving 58 irritable bowel syndrome (IBS) patients reported that it can relieve the disease symptoms and contribute to beneficial alterations in the intestinal microbiota. Galena et al. (2022) [16], in an investigation with 93 healthy women, reported that the consumption of fermented cabbage may be associated with beneficial alterations in the gut microbiota. In a survey conducted by Pathak et al. (2021) [17], the dietary patterns of 131 Polish migrant women (with histological/cytological confirmation of invasive breast cancer) were analyzed concerning their consumption of cabbage and sauerkraut. The findings indicated a correlation between a higher intake of these foods during either adolescence or adulthood and a decreased risk of breast cancer. Fijan et al. (2024) [18], based on various clinical trials analyzed, summarized that the regular intake of brassica fermented products (mainly kimchi) was related to low serum inflammatory cytokines, low adverse fecal enzyme activities (glucosidase and glucuronidase), reduced body fat, and improved metabolic parameters, such as fasting blood sugar, total cholesterol, insulin resistance, lower blood pressure, and improved HDL level.

In the fermentation process of sauerkraut, two main ingredients are used: white cabbage and salt. However, the technique selected and the final product obtained may vary depending on where it is produced. Cabbage is usually cut into thin slices before fermentation. However, in some countries (Croatia and Bosnia Herzegovina), the cabbage is fermented whole in large barrels, making the process much slower. In other regions, apples are used as ingredients during fermentation to sweeten and speed up the processing of sauerkraut. In South Korea, the cabbage is mixed with spices, peppers, radishes, and garlic, among other vegetables, before fermentation, obtaining a much spicier final product (kimchi) [6,19,20]. After fermentation, sauerkraut is packed and sterilized or pasteurized followed by refrigerated storage. During fermentation, there may be the growth of Gram-negative bacteria, such as *Enterobacteriaceae*, *Flavobacterium*, and *Pseudomonas*, as well as fungi, which produce pectinolytic enzymes that will hydrolyze the cabbage pectins and cause unwanted softening (defect) in the fermented product obtained [20].

The production of sauerkraut has been studied to test the utilization of different constituents to improve various characteristics, either organoleptic or nutritional. Examples include the production of sauerkraut with wine and spices (caraway and dill seeds) to enhance aroma and flavor. Others tested different sodium chloride concentrations and salt mixtures (sodium, calcium, potassium, and magnesium chlorides) to lower the concentration of salt in the final product [21–25]. The total or partial salt replacement by *Salicornia ramosissima* (halophyte plant) was also tested [14]. In this study, one of the problems associated with fermented cabbage was the soft texture in some conditions tested. However,

various authors reported that the addition of calcium chloride ($CaCl_2$) in cucumber fermentation brine is a common practice, dating back more than 30 years, to maintain the crispy texture of these vegetables [26–28]. The supplementation of cucumber fermentation mixtures with $CaCl_2$ has been demonstrated to induce faster growth of LAB and a quicker decline in pH cover brine than in brines with NaCl [28,29]. In both studies, a faster decrease in enterobacteria was observed. In table olive fermentation, calcium salts did not affect the growth of LAB [30] and induced a faster decrease in enterobacteria, as observed in various studies [31,32].

S. ramosissima is an annual plant found in saline wetlands extending from the Arctic to the Mediterranean and is common in southern Portugal [33]. It is distinguished by its unique texture and sensorial profile, characterized by a juicy and salty mouthfeel. It may be used as a substitute for salt in food preparation. In addition to its culinary applications, *S. ramosissima* is sold in gourmet shops as a component of mixed green-leaf salads, underscoring its market value and versatility [34,35].

The main objective of this study was to investigate the fermentation of white cabbage supplemented with salicornia and $CaCl_2$, highlighting the innovative potential of local halophyte plants as natural ingredients in fermented products. The study focused on assessing the impact of $CaCl_2$ on the fermentation profile, specifically microbiological properties, pH, and acidity, while also evaluating the final product's microbiological quality and textural characteristics. Furthermore, in the second part of this investigation, the effect of salicornia and $CaCl_2$ on the mineral content of the fermented products obtained was also studied. This work aims to promote salicornia as a sustainable ingredient in fermented foods, offering unique nutritional benefits.

2. Materials and Methods

2.1. Materials

Cabbage (*Brassica oleracea* L., capitata) and salt were bought in supermarkets in the southern part of Portugal. Fresh local *Salicornia Ramosissima* was supplied by the company RiaFresh® [36] on the day when fermentations were set. The culture media and chemicals used in the microbiological and physicochemical determinations were analytical grades obtained from available marketable brands.

2.2. Preparation of Fermented White Cabbage and Sampling

The cabbage was shredded into thin strips (3–5 mm) with a stripping machine after eliminating the outer leaves and the hard-central part and the fresh salicornia was sliced into portions of 0.5 cm. The shredded materials were placed in polyethylene bags (80 cm thick and 1.67 g/m^{2}d permeability). To evaluate the microbiological and physicochemical parameters as well as mineral composition, two experiments were conducted: Experiment A: 80 g of cabbage, 0.4 g of NaCl, and 24 g of salicornia; Experiment B: 80 g of cabbage, 0.4 g of NaCl, 24 g of salicornia, and 1.28 g $CaCl_2$. The mineral compositions in the final fermented products obtained were compared to Experiment C: 80 g of cabbage and 0.4 g of NaCl; and Experiment D: 80 g of cabbage and 24 g of salicornia. The mass of salicornia was calculated to obtain fermentation mixtures with a Na concentration not exceeding 0.5% when compared to the commercial fermented cabbage, according to previous experiments described in Pires-Cabral et al. (2022) [14]. The Na calculation was performed considering the mineral composition of salicornia reported by Barreira et al. (2017) [34].

The ingredients were well distributed in the bags and gently compressed. Using a packing/sealing machine (Quick Pack, Speedy, Italy), the bags were sealed with a moderate vacuum (2 out of 10) and an intermediate seal (3 out of 10). Each experiment was performed in duplicate. Fermentation took place at 20 °C for 20 days. Two samples (two bags) were taken

on each sampling day (0, 2, 6, 8, 13, and 20) and microbiological (LAB, fungi, and coliforms) and physicochemical analyses (pH, acidity) were carried out during the fermentation period. At the end of the fermentation (day 20), the minerals (sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), and zinc (Zn)) were also quantified. The quantification of minerals in fermented cabbage A and B (resulting from Experiments A and B) was compared to the fermented cabbage C and D (resulting from Experiments C and D).

2.3. Microbiological Analyses

The levels of lactic-acid bacteria (LAB), fungi, and coliforms were measured on each sampling day during the fermentation period. Microbiological analyses (LAB and fungi) were performed according to the International Organization for Standardization (ISO) procedures. Aliquots of serially diluted samples were inoculated into appropriate media. LAB were enumerated as described in ISO 15214, British Standard (1998) [37], by plating 1 mL aliquots on MRS agar (Scharlau, Barcelona, Spain) after incubation for 3–5 days at 30 °C. Enumeration of fungi was performed according to ISO 21527-1 (2008) [38] by plating 0.1 mL aliquots on Dichloran Rose Bengal Chloramphenicol Agar (Biolife, Milan, Italy) after incubation at 25 °C for 5–7 days. Coliforms were counted on Chromocult agar (Merck, Darmstadt, Germany) and incubated at 37 °C for 24 h [39]. Coagulase-positive staphylococci were assessed by inoculating 0.1 mL of the dilutions onto Baird–Parker medium (Oxoid, Basingstoke, UK), followed by incubation at 37 °C for 24–48 h, according to ISO 6888-1 (1999; Amd 1:2003) [40]. ISO 6579-1 (2017) [41] was followed to detect *Salmonella* sp. in the fermented samples. The microbial analyses were performed in two sets of experiments for each condition. At each sampling point, the studies were conducted in duplicate and the colony-forming units (CFU) were expressed as Log CFU/g cabbage.

2.4. Physicochemical Analyses

A Crison GLP 21 (Barcelona, Spain) digital pH meter was used to measure the pH of the brines at 21 °C [42]. Free acidity was determined by titrating 10 mL of brine, previously added to 50 mL of distilled water, with 0.1 N NaOH to pH 8.2 [43] (g lactic acid/100 mL brine (%, *w*/*v*)). Acidity and pH were measured in three replicates.

2.5. Mineral Determination

To quantify the mineral composition (sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), and zinc (Zn)), one gram of the dry fermented material obtained from Experiments A, B, C, and D was oven-dried in a muffle furnace (Nabertherm, LT 9/11, Lilienthal, Germany) at 500 °C for seven hours. Subsequently, 10 mL of 37% hydrochloric acid (Riedel-de Haen, Seelze, Germany) was added to the ashes until whitish smoke and a yellowish color were observed. Subsequently, the samples were filtered using Whatman Nº 42 paper (Cytiva, Marlborough, MA, USA), and the volume was adjusted to 100 mL. The contents of the minerals were quantified by flame atomic absorption spectrophotometry in the air-acetylene flame using an Analytik Jena NovAA 800 (Jena, Germany), following the specific programs for each metal and the requisite adjustments to minimize matrix interferences. The metal content was measured based on calibration curves prepared with available concentrated metal solutions (1000 mg/L) in accordance with the procedures set forth by the AOAC (1995) [44]. The mineral content was expressed in grams per kilogram of dry weight (g/kg (dw)). Experiments were conducted in triplicates and averages and standard deviation were reported.

2.6. Texture

The texture of the raw and fermented cabbage samples with and without $CaCl_2$ was determined using a texturometer (Brookfield, LFRA 1500, Middleborough, MA, USA)

following the method described by Cruz et al. (2016) [45]. This instrument has a 1.5 kg load cell and a stainless-steel probe (TA-39) with a flat end, 2 mm in diameter and 20 mm long, that was used to penetrate the samples. Portions of fermented and non-fermented cabbage were placed between two metal plates with a cylindrical hole (diameter = 15 mm) in the center. The test speed was set at 0.5 mm/s and the penetration distance was 10 mm. The maximum force and the area under the respective curve were used to quantify the hardness (N) and the work needed to deform the specimen (N.m), respectively. The above texture attributes were obtained using Texture ProLite V1.1 software. From each bag, 10 portions of cabbage were selected for analysis, resulting in 20 measurements at each sampling point. The results presented are the mean and standard deviation of the 20 measurements.

2.7. Sensorial Analysis

Once the cabbage had been fermented and the results of the microbiological analysis had been obtained to assess the hygiene and safety conditions of the samples, sensory analyses were carried out with a panel of 18 untrained tasters, of both sexes aged between 20 and 60 years, who were used to tasting fermented foods. The tasting room had individual tasting booths, air conditioning at 20 °C, 70% RH, and white LED lighting. Each taster was given a data sheet with the parameters to be evaluated, a tray with samples A and B, randomly coded with three-digit numbers, and a mouth rinse (water). They were asked to rate the organoleptic parameters appearance, color, aroma, hardness, acidity, salt content, and taste and to provide an overall rating on a 5-point hedonic scale, where: for appearance, color, aroma, taste and overall rating, 1 indicates unpleasant and 5 very good or excellent; for hardness, 1 indicates very soft and 5 very hard; for acidity, 1 indicates no acidity and 5 very acidic; and for salt content, 1 indicates no salty taste and 5 very salty.

2.8. Statistical Analyses

Experimental values were expressed as the mean of several measurements (depending on the analysis method) and the standard deviation. After checking the normality of the data (Shapiro–Wilk test) and the homogeneity of the variances (Levene test), one-way ANOVA was carried out to test for significant differences between the means of the groups at a significance level of 5%. A Scheffé post-hoc test was used to indicate significant differences between means at least the 5% level.

The Student's test was used to compare the texture data of the raw and fermented cabbage samples with and without $CaCl_2$. The analysis was performed at a 5% significance level. All statistical analyses were performed using SPSS statistical software, version 29.0 (IBM SPSS Statistics 29.0).

3. Results and Discussion

3.1. Microbiological Profile

The processing of sauerkraut involves a series of fermentation stages, consisting of an initial heterofermentative phase and a subsequent homofermentative phase. At the beginning of the fermentation processes, the number of LAB was 2.18 ± 0.83 and 1.93 ± 0.93 Log CFU/g in Experiments A and B, respectively. The LAB populations increased exponentially during the first two days and then decreased slightly until day 20th. At the end of the fermentation, there were no significant differences ($p < 0.05$) between the LAB populations (6.01 ± 1.02 and 5.51 ± 0.12 Log CFU/g) of both fermented cabbages (Figure 1).

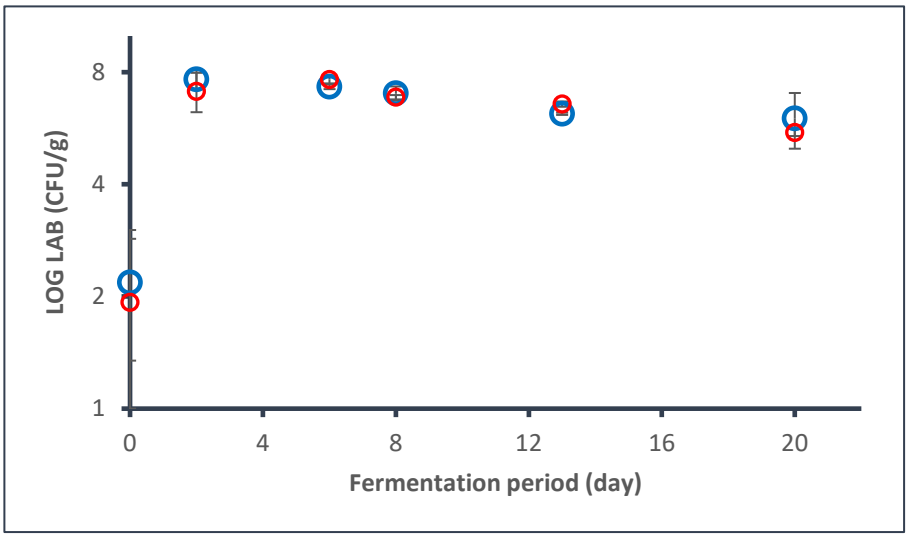

Figure 1. Changes of lactic-acid bacteria (LAB) population during white cabbage fermentation: Experiment A—Cabbage+salt+salicornia (blue symbols), and Experiment B—Cabbage+salt+salicornia+$CaCl_2$ (red symbols).

The growth of LAB in this study followed the same behavior as reported by other authors [14,22,46]. In fact, according to Zabat et al. [46], during the initial phase of fermentation, the predominant species present include heterolactic LAB with reduced acid tolerance, such as *Leuconostoc* and *Weissella* species, in addition to Gram-negative species belonging to the Enterobacteriaceae family and *Pseudomonas*. Subsequently, more acid-tolerant homolactic fermenting LAB species, namely *Lactobacillus* and *Lactococcus*, initiate growth and dominate the fermentation process until its completion [46]. Heterolactic and homolactic metabolisms of LAB play a crucial role in fermentation, converting cabbage nutrients into weak organic acids (primarily lactic acid), ethanol, CO_2, bacteriocins, and various secondary metabolites. This process helps reduce spoilage, enhance microbial safety, and improve the sensory properties of fermented foods. Undesirable compounds, such as nitrite, a precursor of nitrosamine (a carcinogenic compound), are also reduced during fermentation as a result of LAB activity, as observed in pepper fermentation [47]. Beyond their role in fermentation, LAB also offers functional benefits. Specific species and strains contribute to improved nutritional properties by synthesizing vitamins and bioactive peptides, reducing anti-nutritional factors, and increasing the bioavailability of essential nutrients such as proteins and minerals. Additionally, they enhance fermented foods' antioxidant and anti-inflammatory properties, providing significant health benefits. LAB metabolites, including weak organic acids, hydrogen peroxide, and bacteriocins, are essential for regulating gut microbiota and strengthening immune function [47,48].

The fungal populations (Figure 2) at the beginning of the process were 2.68 ± 1.19 and 3.09 ± 0 Log CFU/g in Experiments A and B, respectively. As Pires-Cabral et al. (2022) [22] observed, including salicornia in the fermentation mixtures resulted in higher fungal populations. However, a reduction in this microbial group was observed, with no further detection (below the limit of detection) after the sixth day of fermentation (Figure 2). Compounds produced during lactic acid metabolism act as biopreservatives, inhibiting the growth of spoilers, such as fungi, whose presence is undesirable as they may contribute to the softening of the fermented product and impart disagreeable organoleptic characteristics to the final product [49–53].

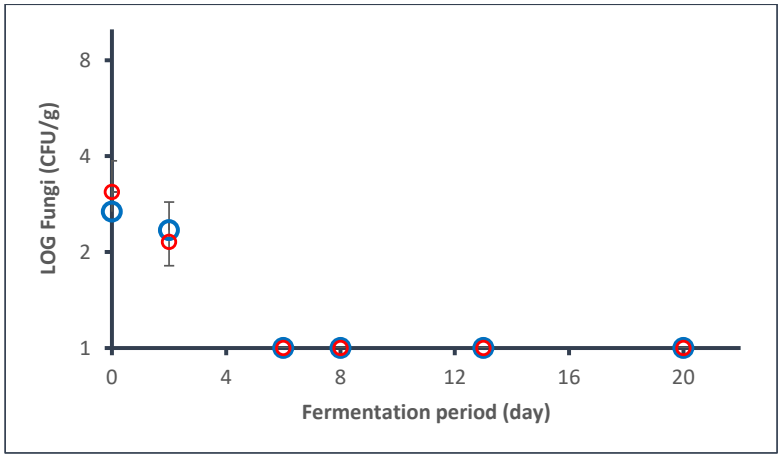

Figure 2. Changes in fungi population during white cabbage fermentation: Experiment A—Cabbage+salt+salicornia (blue symbols) and Experiment B—Cabbage+salt+salicornia+$CaCl_2$ (red symbols).

The enumeration of coliforms at the beginning of the processes showed values of 2.49 ± 1.27 and 3.09 ± 0 Log CFU/g in Experiments A and B, respectively (Figure 3). An increase in the number of coliforms was observed during the first 2 days, with maximum values of 4.9 ± 0 and 4.11 ± 0.14 Log CFU/g in processes A and B, respectively, after which a decrease was observed until their disappearance after day 13 in Experiment B. At the end of fermentation, coliforms were detected at levels below the detection limit. The presence of $CaCl_2$ in the brines of table olives and cucumber fermentations also caused a faster disappearance of the enterobacterial population from the processes [29,32]. This microbial population is part of the natural biota during the initial stages of cabbage fermentation [46]. It seems reasonable to conclude that the disappearance of fungi and coliforms is due to the selective pressure exerted by the fermentation environment. In the case of cucumbers [29] and black carrot fermented beverages [54], accelerated sugar utilization in the presence of $CaCl_2$ compared to NaCl brines resulted in the production of more weak organic acids and a greater decrease in pH, which may explain the faster reduction of enterobacteria observed in fermented cucumbers. In table olives, Garcia Serrano [30] mentioned that the presence of calcium slows down the diffusion of various compounds from the fruit into the surrounding fermentation liquid, which may affect the growth of enterobacteria (if compounds/nutrients are determinants of their growth, for example).

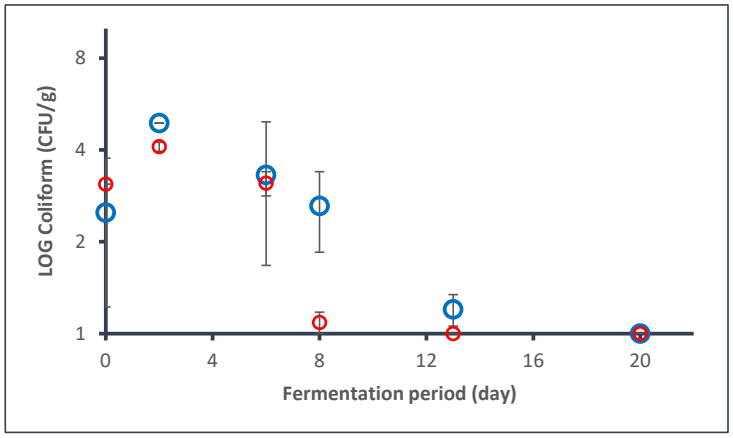

Figure 3. Changes in coliform population during white cabbage fermentation: Experiment A—Cabbage+salt+salicornia (blue symbols) and Experiment B—Cabbage+salt+salicornia+$CaCl_2$ (red symbols).

In addition, at the end of the fermentations, fermented cabbage A and B samples were also analyzed for the presence of coagulase-positive *Staphylococcus*, *Escherichia coli*, and *Salmonella* sp. The results confirmed the absence of these microorganisms in all the fermented cabbage obtained.

3.2. Physicochemical Profile

The obtention of adequate pH and acidity levels at the end of the fermentations is mandatory as these parameters are determinants to inhibit any undesirable bacteria or fungi from growing. The pH values decreased from 5.86 ± 0.01 and 5.72 ± 0.01 to 4.07 ± 0.01 and 3.58 ± 0.01 at the end of fermentations A and B, respectively (Figure 4). The $CaCl_2$ content had a significant effect ($p < 0.05$) on decreasing pH, showing that this mineral may be used as an ingredient in the fermentation of white cabbage. The free acidity in Experiments A and B rose from 0.045 ± 0 and 0.036 ± 0.01 to 0.70 ± 0.01 and 0.77 ± 0.01 g lactic acid/100 mL (%, *w*/*v*), respectively, at the end of fermentation.

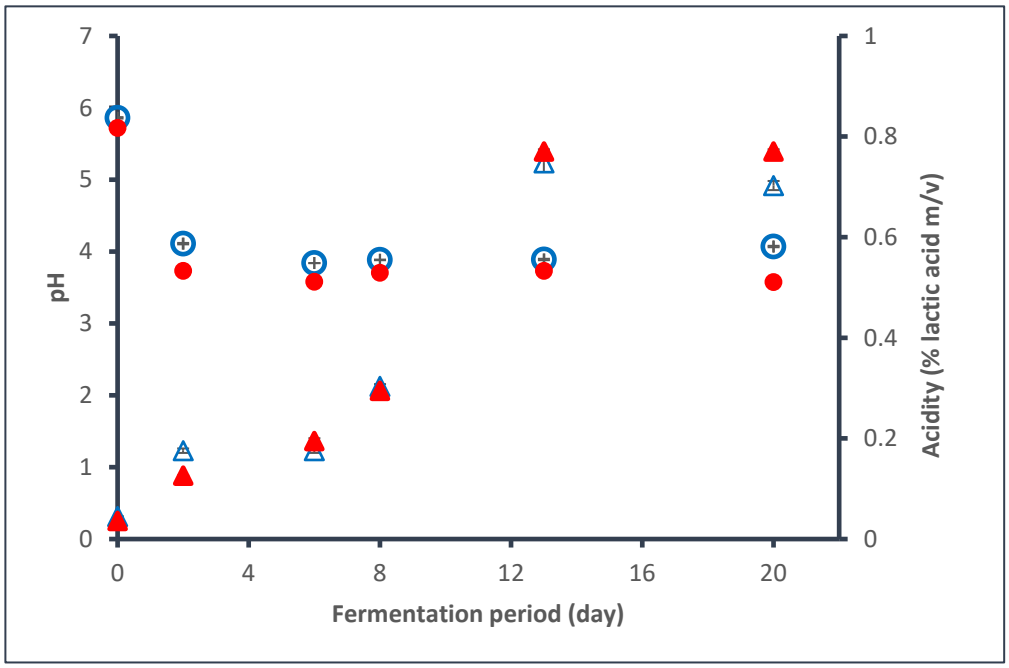

Figure 4. Changes of pH (circular markers) and acidity (triangular markers): Experiment A—cabbage+salt+salicornia (open symbols) and Experiment B—cabbage+salt+salicornia+$CaCl_2$ (closed symbols).

This acidification resulted from the diffusion of organic acids from the cabbage and salicornia tissues into the brine and the production of weak organic acids (lactic acid, among others) through the fermentative metabolism of LAB [55]. The presence of Ca had a significant effect ($p < 0.05$) on the free acidity of the fermented white cabbage obtained from both fermentations. The values attained for pH and acidity correspond well with other studies [22,56,57] and align with the regulatory limits established for other fermented foods, such as natural table olives, to ensure microbiological stability and extend the shelf-life of this type of product [58]. $CaCl_2$ in the fermentation mixtures led to a higher production of weak organic acids, which resulted in lower pH values in fermented cucumbers [29] and black carrot fermented beverages [54], as mentioned before.

3.3. Texture

The fermented cabbage hardness increased during the fermentation process progression, as evidenced in Table 1. At the beginning (Day 0), the cabbage in Experiment B already

exhibited greater hardness (4.3 N) compared to Experiment A (2.7 N). This suggests that the addition of $CaCl_2$ contributed to increased initial firmness, likely due to the role of calcium in strengthening cell wall structures. By the end (Day 20), both experiments showed a significant increase in hardness, but the increase was more pronounced in B (6.3 N) than in A (4.4 N). This indicates that $CaCl_2$ played a role in preventing textural degradation during fermentation, maintaining firmness over time. The work required to deform the cabbage was higher in Experiment B from the beginning (12.2 mN.m vs. 7.0 mN.m in A), reflecting the greater resistance of cabbage treated with $CaCl_2$. After 20 days, the increase in work for B (21 mN.m) was significantly higher than for A (10 mN.m), reinforcing the idea that $CaCl_2$ effectively stabilizes texture and makes the cabbage more resistant to structural breakdown during fermentation. These effects align with previous studies. The addition of $CaCl_2$ is known to enhance firmness by binding to pectins in the cell wall, forming calcium-pectate complexes that strengthen the structure [59]. Ca is pivotal in preserving vegetable firmness at low pH values by interacting with cell wall polysaccharides. The addition of Ca increased the hardness of the final product of Experiment B. $CaCl_2$ was also effective in delaying softening and maintaining the crispness of various fermented foods, such as cucumbers [28,29] and olives [30].

Table 1. Texture parameters of fermented cabbage from Experiment A and Experiment B.

Parameters	Experiment A Cabbage+Salt+Salicornia		Experiment B Cabbage+Salt+Salicornia+$CaCl_2$	
	Start Day 0	End Day 20	Start Day 0	End Day 20
Hardness (N)	2.7 ± 0.5^{a}	4.4 ± 0.7^{b}	4.3 ± 0.1^{b}	6.3 ± 0.1^{c}
Work (mN.m)	7.0 ± 1^{a}	10 ± 2^{ab}	12.2 ± 0.1^{b}	21 ± 3^{c}

Each value is the mean ± standard deviation of 20 cabbage portion measurements (10 from each bag). Different letters in the same line indicate significant differences ($p < 0.05$) following Student's *t*-test.

3.4. Determination of Minerals

The mineral compositions (g/kg (dw)) of the fermented cabbages obtained from Experiments A and B were compared to fermented cabbages processed with salt (Experiment C) and salicornia (Experiment D), and the results are detailed in Table 2. The levels of the macro minerals, except sodium (Na) and calcium (Ca), found in the final fermented products followed a descending order: potassium (K), zinc (Zn), and magnesium (Mg). The levels of Na and Ca are related to the initial concentrations of the added chloride salts (NaCl and $CaCl_2$) in the fermentation mixtures. The diffusion of Ca into the cabbage tissues caused a decrease in the Na content and affected the levels of the other salts in the final fermented products. The K content of Experiment A (fermented cabbage+salt+salicornia) was 31.34 g/kg, which was significantly higher ($p < 0.05$) than that of Experiment B, 28.84 g/kg, where Ca was added to the fermentation mixture. A significantly lower value was measured in fermented Experience C (cabbage+salt), registered at 24.13 g/kg (<0.05). Significant differences ($p < 0.05$) regarding Zn levels of 10.29 and 6.52 g/kg were found in fermented products obtained from Experiments A and B, respectively, while fermented Experiment D (cabbage+salicornia) contained 14.91 g/kg, the highest value ($p < 0.05$). The Mg content was significantly different ($p < 0.05$) in the four experiments, ranging from 3.03 g/kg to 1.27 g/kg, while for Experiments A and B, 2.62 g/kg and 2.19 g/kg were measured, respectively. The inclusion of salicornia as an ingredient in the processing of fermented cabbage contributes to a significant ($p < 0.05$) enrichment of K, Zn, and Mg in the final products. However, adding $CaCl_2$ may interfere with these minerals' diffusion, significantly reducing ($p < 0.05$) their concentration in the final fermented products. The

Ca content in the fermented cabbage ranged from 25.50 g/kg (Experiment B) to 0.89 g/kg (Experience C). The Na content ranged from 120.95 g/kg (Experience C) and 38.8 g/kg (Experience D). The inclusion of salicornia in the fermentation mixture contributes to a significant reduction ($p < 0.05$) in the Na content of the final product, as noticed in Experiment A with 62.27 g/kg of Na and a significantly increased concentration of K, Mg, and Zn. Halophytes such as *S. ramosissima* grow in saline environments and have a high capacity to accumulate Na, K, Ca, Mg, and Fe salts, making these plants valuable sources of essential minerals [60]. Their utilization in food preparations, including fermented foods, contributes to the enrichment of various minerals [34]. Ca also reduced Na in the final product (55.63 g/kg) by about 10.66%. However, adding $CaCl_2$ to the fermentation medium significantly decreased the content of other minerals in the fermented cabbage, namely the macro-elements K by 7.85% and Mg by 16.41% and the micro-element Zn by 36.64%. This effect has also been reported in fermented table olives [61]. $CaCl_2$ should be cautiously added in fermentation mixtures since it may adversely affect the mineral composition of the final products.

Table 2. Mineral composition (g/kg (dw)) of fermented cabbages obtained at the end of Experiments A, B, C, and D.

Fermentations	Na	K	Ca	Mg	Zn
Experiment A Cabbage+salt+salicornia	62.27 ± 1.45 ^{c}	31.34 ± 0.455 ^{c}	1.28 ± 0.110 ^{a}	2.62 ± 0.070 ^{c}	10.29 ± 0.614 ^{b}
Experiment B Cabbage+salt+salicornia+$CaCl_2$	55.63 ± 1.34 ^{b}	28.84 ± 0.549 ^{b}	25.50 ± 3.673 ^{b}	2.19 ± 0.125 ^{b}	6.52 ± 0.740 ^{a}
Experiment C Cabbage+salt	120.95 ± 1.54 ^{d}	24.13 ± 0.09 ^{a}	0.89 ± 0.101 ^{a}	1.27 ± 0.034 ^{a}	7.38 ± 1.760 ^{ab}
Experiment D Cabbage+salicornia	38.83 ± 1.48 ^{a}	31.33 ± 0.338 ^{c}	2.25 ± 0.116 ^{a}	3.03 ± 0.036 ^{d}	14.91 ± 0.604 ^{c}
***p*-value**	<0.01	<0.01	<0.01	<0.01	<0.01

Each value is the mean ± standard deviation of two fermented cabbage samples. Different letters in the same column indicate significant differences according to Scheffe's multiple-range test ($p < 0.05$).

3.5. Sensorial Analysis

The fermented cabbage produced in the presence of $CaCl_2$, Experiment B, was also sensory evaluated with the cabbage from Experiment A. The panel of tasters did not detect significant differences in sensory attributes between the analyzed products ($p < 0.05$). The two fermented cabbages, A and B, were classified with similar values in all attributes, including flavor (3.2 ± 0.8; 2.5 ± 0.9, respectively), global appreciation (3.2 ± 0.8; 2.5 ± 0.9, respectively), aspect (3.8 ± 0.9; 3.4 ± 0.9, respectively), color (3.9 ± 0.8; 3.5 ± 0.9, respectively), aroma (3.3 ± 0.7; 3.0 ± 0.7, respectively), acidity (2.9 ± 0.9; 3 ± 1, respectively), hardness (3.3 ± 0.9; 3.7 ± 0.9, respectively), and salt content (2.8 ± 0.6; 2.6 ± 0.8, respectively).

4. Conclusions

The presence of calcium did not affect the growth of lactic-acid bacteria during the fermentation process, resulting in pH and free acidity levels that contributed to the disappearance of fungi and coliforms in the final products. In addition, *Escherichia coli*, *Staphylococcus*, and *Salmonella* sp. were not detected at the end of the fermentations. Incorporating Salicornia into the fermentation mixtures resulted in a reduction of Na and an enrichment of minerals, especially Zn, in the fermented cabbage. On the other hand, the addition of Ca interfered with the diffusion of K, Zn, and Mg, resulting in reduced levels in the final product. However, it contributed to an increase in the hardness of the fermented cabbage and a rapid decrease in the coliform population. The results of this study could be used to obtain fermented cabbage with healthier mineral profiles using Salicornia as an ingredient while maintaining the traditional characteristics. Future research will evaluate

the effects of different calcium concentrations that do not interfere with mineral diffusion and other local halophytes to understand their influence on fermentation, guarantee of microbial safety, and improvement in nutritional final product properties.

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