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Original Article

Suitability of Sprouted and Fresh Three Potato Cultivars for Chip Manufacture: A Chemical and Sensory Evaluation

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Abstract: Potatoes are a globally important crop and a key raw material for the production of chips. Sprouting during potato storage is a critical problem that alters chemical and sensory attributes such as sugar accumulation, starch reduction, and firmness loss, which negatively affect chip quality. However, limited studies have addressed these changes across cultivars under local conditions. The present study explored the influence of fresh potato (at harvest) and sprouting stages (non-sprouted, and sprouted at 1 cm and 2 cm length) on the chemical properties and sensory quality of three potato chip cultivars (Crozo, Hermes, and Lady Rosetta), which are widely grown in the Kurdistan Region of Iraq. To ensure clarity of the experimental design, the study specifically evaluated these three cultivars across four developmental stages to assess their chemical and sensory quality for chip production. After that, the results indicated that Crozo exhibited the highest dry matter (29.78%) and starch (22.53%) at 2 cm sprouting, indicating strong frying potential. Lady Rosetta exhibited the least weight loss (5.85%) and the highest firmness (33.02 N) at harvest. TSS increased after storage, peaking in Lady Rosetta (8.67 %), while total sugar content decreased during sprouting to 0.089%. Sensory scores for chips declined with increased sprout length. Crozo and Lady Rosetta maintained a better appearance, flavor, and texture during the sprouting stages than Hermes. Overall, the cultivar and sprouting stages had a significant influence on quality. Fresh and non-sprouted potatoes are recommended for optimal chip quality. The results concluded that Crozo and Lady Rosetta cultivars are most suitable for storage conditions and processing due to their favorable chemical traits and sensory performance.

1. Introduction

Potatoes (*Solanum tuberosum*) are among the most widely consumed crops worldwide and offer a rich source of carbohydrates, vitamins, and minerals essential for human nutrition [1, 2]. Owing to their versatility, potatoes are used in a wide range of culinary preparations, from raw consumption to cooking, roasting, frying, and processing into products, such as chips and instant mashed potatoes. Among these, potato chips are especially popular because of their convenience, taste, and variety of flavors, and represent a significant segment of the global snack food industry. The global production of potatoes is vast, with the total global output reaching approximately 223 million tons [3, 4].

Iraq, a significant potato producer in the Middle East, had an estimated total production of 1.5 to 1.7 million tons in 2024, with a substantial contribution from the Kurdistan Region, which alone produced between 800,000 and 1,000,000 tons. Within the Kurdistan Region, Duhok Governorate saw a remarkable 902% growth in potato output from 2019 to 2024, highlighting the importance of this crop to the local agricultural economy. These figures are supported by data from the Food and Agriculture Organization and Media and Information Office of the Kurdistan Regional Government.

Potato quality is crucial in the food industry, especially for products such as chips [5]. Several chemical factors, including dry matter content, starch concentration, total sugars, and total soluble solids (TSS), determine the quality of potato tubers [6]. These parameters significantly influence the processing behavior of the tubers and the final quality of the processed products. Potatoes with elevated dry matter and starch levels tend to produce superior chips, exhibiting desirable characteristics, such as crispness, texture, and flavor [7, 8]. Conversely, potatoes with high sugar content, especially reducing sugars, can undergo undesirable browning during frying, leading to a decline in product quality [9, 10]. Storage conditions and sprouting process are two critical factors that affect these chemical parameters [7, 11]. Storage at optimal temperatures and humidity levels can preserve the quality of tubers and prevent defects, such as low-temperature sweetening, which negatively impacts taste, color, and texture [12, 13]. However, sprouting, a natural physiological response, can cause changes in starch metabolism, leading to alterations in the chemical composition of the tuber [6]. Sprouted potatoes often experience a breakdown of starch into sugars, which can increase reducing sugars and, subsequently, cause undesirable changes in chip quality [1]. Recent studies have confirmed that sprouting accelerates starch hydrolysis, increases reducing sugar levels, and elevates glycoalkaloid concentrations, which compromise frying quality and consumer safety. Additionally, these changes are cultivar-dependent, with some varieties showing greater tolerance to sprouting than others [14, 15].

Given the nutritional importance of potatoes, which are widely used for cooking, frying, and chip production, it is crucial to consider the influence of sprouting on the chemical composition and sensory quality of potato chips, as these effects differ among cultivars. These chemical alterations can potentially lead to the accumulation of compounds that are undesirable and harmful to human health. The originality of this study lies in its integrated assessment of both chemical and sensory attributes across three major cultivars that are widely grown in the Kurdistan Region of Iraq. To our knowledge, this is the first study in the region to systematically link sprouting stage, cultivar characteristics, and chip quality, providing evidence-based recommendations for industrial processing and storage practices. Therefore, this study focused on the chemical changes and sensory quality of three potato cultivars (Hermes, Lady Rosetta, and Crozo) during sprouting to evaluate their suitability for chip production. The main aim of the study was to examine the effects of sprouting on the key chemical and sensory traits of the three cultivars of potatoes. The analysis is intended to identify the potential of each cultivar for industrial processing so that the final products can reach the level of quality required to meet the needs of consumers.

2. Materials and Methods

2.1. Sample Collection and Storage

Crozo, Hermes, and Lady Rosetta potato tubers, which are commonly used for chip processing and are increasingly cultivated in the Kurdistan Region for this purpose, were selected for this study. Seventy kilograms of each cultivar were collected from a field in the Penjwen District of Sulaimania Governorate, Kurdistan Region, Iraq, and only healthy, medium-sized tubers were selected. The tubers were carefully washed with tap water to eliminate soil and debris and air-dried at room temperature. Ten kilograms of each cultivar were immediately used for the initial chemical analysis (at harvest), while the remaining 60 kg was divided into three replicates and placed in perforated plastic net bags for storage. They were then stored at 10 ± 1 °C with 85-90% relative humidity (RH) [16, 17] until sprouting started on tubers with lengths of 1 cm and 2 cm. During the storage period, the tubers were regularly inspected for sprouting and decay. Crozo tubers were stored from September 11, 2024, to November 17, 2024 (68 days), with visible sprout growth recorded on November 3, 2024. Hermes tubers were stored from September 11, 2024, to November 28, 2024 (79 days), and sprouting was observed on November 10, 2024. Lady Rosetta tubers were stored from October 24, 2024, to February 25, 2025 (125 days), with sprout emergence noted on January 26, 2025.

2.2. *Studied Parameters*

2.2.1. Weight Loss

To evaluate weight loss during storage, initial weights were recorded on September 10, 2024, using a digital electronic balance (YD, China), and upon completion of the storage period, they were weighed to determine their final weight. The following formula was used to calculate the weight loss for each replicate [17, 18]:

$$\text{Weight loss (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} * 100 \qquad (1)$$

2.2.2. Tuber Dry Matter

The DM content was assessed using random tuber samples. Approximately 10 ± 1 g of fresh tuber tissue was sampled from each replicate and dried in an electric oven (Memmert UNB 100 Oven-Gemini BV) at 70 °C until a stable weight was achieved. The dry matter percentage was determined by applying the following formula [19, 20]:

$$\text{Dry matter (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} * 100 \qquad (2)$$

2.2.3. Estimation of Starch in Potatoes

The starch content in potato tubers was estimated from the dry matter percentage using the equation outlined by the Association of Official Analytical Chemists (AOAC), 2012 [21]:

$$\text{Starch(\%)} = 17.55 + 0.89\text{x (Dry Matter(\%)} - 24.18) \quad (3)$$

In this equation, the constant 17.55 represents the baseline starch percentage at a standard dry matter value, and 0.89 is a regression coefficient that adjusts the starch estimate based on deviations from the reference value (24.18%). This relationship is widely applied in potato processing research because dry matter and starch content are strongly correlated and jointly determine frying quality parameters, such as crispness, color, and oil uptake [20].

2.2.4. Determination of Total Sugars

The total sugar content of potato tubers was measured following the method outlined by Joslyn [22]. One milliliter of potato juice was transferred into a 50 mL volumetric flask, to which 1 mL of 5% phenol solution was added, followed by approximately 18 mL of distilled water. Subsequently, 5 mL concentrated sulfuric acid was added. The mixture was incubated in a water bath at 60 °C for 30 min. After incubation, the solution was filtered and the absorbance of the filtrate was measured at 490 nm using a spectrophotometer (Shimadzu Pharmaspec UV-1700/ Japan). Total sugar content was calculated using the following formula [23]:

$$\text{Total sugar} = \text{Absorbance reading} * \text{Dilution} * 0.0525 * 100 \qquad (4)$$

2.2.5. Total Soluble Solids

The TSS of potato pieces was assessed using a hand-held refractometer (ATAGO CO. LTD, Japan) according to the AOAC standard procedure [21, 24].

2.2.6. Firmness (N)

Tuber firmness was assessed using a Texture Analyzer (Brookfield CT3-1000 Texture Analyzer, USA). The tubers were then peeled and placed on an instrument platform. A probe with a diameter of 3 mm is used to compress the tuber. The crosshead moved downward at a speed of 10 mm/s to a depth of 10 mm [25].

2.2.7. Chips Processing

Potato chips were prepared from three cultivar tubers at four different stages: freshly harvested and post-storage (without sprouting, with sprouts of 1 cm and 2 cm in length). Processing followed the Kurdistan regional standard protocol used in commercial chip manufacturing. The tubers were initially thoroughly washed under running tap water to eliminate soil and surface impurities. Following cleaning, they were manually peeled and sliced uniformly to a thickness of 0.5–1 mm using a vegetable slicer. The slices were then soaked in clean water for 30 min to reduce the surface starch and prevent enzymatic browning [26]. Following soaking, the slices were drained and blotted with paper towels to remove excess moisture [5, 27]. Frying was performed in palm olein (vegetable oil) at a temperature of 180 ± 2 °C using a thermostatically controlled deep fryer (Princess 182727 model). Once the slices reached a golden and crisp texture, they were removed from the oil, drained of excess oil, and uniformly salted. Salting was performed following the Kurdistan standard protocol for chip production to ensure consistency with industrial practices [28].

2.2.8. Sensory Evaluation of Potato Chips

The sensory evaluation was conducted on chips made from the studied potato cultivars by 10 participants of both sexes, aged between 18 and 54 years. The participants included lecturers, employees, and undergraduate and postgraduate students from the Technical College of Halabja, Sulaimani Polytechnic University.

Evaluation forms were used to assess the following sensory attributes: appearance, color, texture, flavor, and overall acceptability. The overall acceptability was determined by averaging the scores for appearance, color, texture, and flavor. The evaluation scores ranged from 1 to 9 on a 9-point hedonic scale, where 1 = extremely dislike, 2 = very much dislike, 3 = moderately dislike, 4 = slightly dislike, 5 = neither like nor dislike, 6 = slightly like, 7 = moderately like, 8 = very much like, and 9 = extremely like [29, 30].

2.3. Statistical Analysis

This study was conducted using Analysis of Variance (ANOVA) in a completely randomized design with two factors (cultivar and sprouting stage) and three replicates. The mean data were compared using Duncan's multiple range test. The study data were analyzed using XLSTAT-Premium 2016.02.28451 software.

3. Results

3.1. Weight Loss

Notable differences in weight loss percentage across the three cultivars, Crozo, Hermes, and Lady Rosetta, were observed for potato tubers (Figure 1). Crozo exhibited the highest weight loss percentage (12.20%), closely followed by Hermes (10.51%). In contrast, Lady Rosetta showed the lowest weight loss (5.85%). Statistical analysis confirmed that weight loss in Lady Rosetta was significantly lower than that in both Crozo and Hermes, whereas no significant difference was found between Crozo and Hermes.

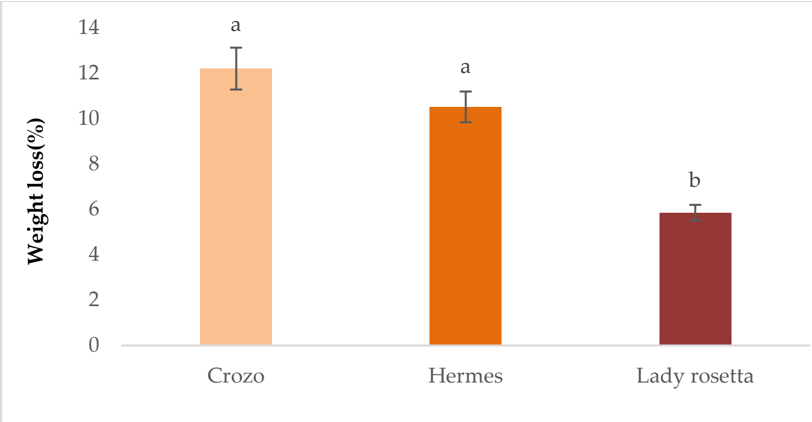

Figure 1: Weight loss of three potato cultivars, storage durations until measurement. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.

3.2. *Tuber Dry Matter*

ANOVA revealed significant effects of cultivar, sprouting stage, and their interaction on the tuber dry matter content. The dry matter content of potato tubers was evaluated across three cultivars (Crozo, Hermes, and Lady Rosetta) at the harvest and sprouting stages (non-sprouted, 1 cm sprouts, and 2 cm sprouts). The results revealed significant differences between cultivars and sprouting stages. Statistical analysis showed that Crozo differed significantly from both Hermes and Lady Rosetta in terms of dry matter content, whereas the latter two cultivars showed no significant differences. Crozo tubers exhibited the highest dry matter content (27.35%), followed by Hermes (25.67%), and Lady Rosetta (25.35%) (Figure 2).

The sprouting stage has a statistically significant effect on the dry matter content of tubers. The greatest dry matter value was recorded at the 2 cm sprouting stage (27.19%), followed by the "at harvest" (25.97%) and 1 cm sprouting (25.76%) stages. The minimum dry matter content was found in non-sprouted tubers (25.58%) (Figure 2).

Figure 2: Dry matter content of potato cultivars and sprouting stages. Different letters on each factor indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.

The interaction between cultivars and sprouting stage was statistically significant, revealing varying dry matter accumulation patterns among cultivars and sprouting stages (Figure 3). The highest dry matter was measured in Crozo at the 2 cm sprouting stage (29.77%), followed closely by Hermes at the 1 cm stage (29.69%), which differed significantly from all other interaction treatments except the Lady Rosetta at harvest (27.96%). Lower values were found in Lady Rosetta at 1 cm sprouting (20.79%), which was significantly different from all others.

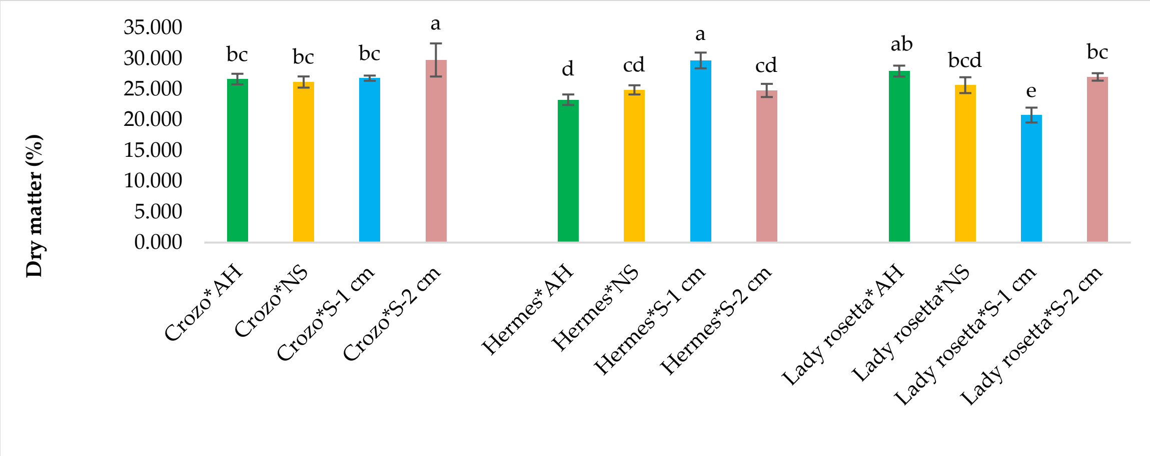

Figure 3: Interaction between cultivars and sprouting stages on dry matter content. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.
AH=At harvest, NS=Non-sprout, S=sprouts

3.3. Starch Content

The starch content varied significantly among the three potato cultivars examined. Crozo exhibited the highest starch content (20.37%), followed by Hermes (18.87%) and Lady Rosetta (18.59%). Statistical analysis confirmed that Crozo was significantly different from the other two cultivars, with no significant difference between them (Figure 4).

Starch content is significantly influenced by the sprouting stage. The highest starch level was recorded at the 2 cm sprouting stage (20.23%), followed by the harvest stage (19.14%) and the 1 cm sprouting stage (18.96%). The lowest starch content was observed in non-sprouted tubers (18.79%). The 2 cm sprouting stage was significantly different from all other stages (Figure 4).

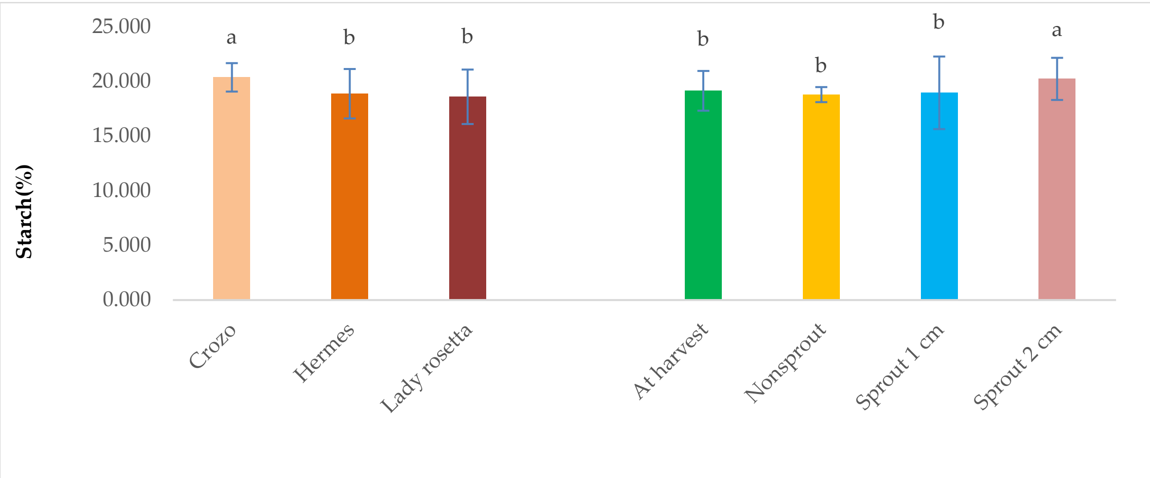

Figure 4: Starch content of potato cultivars and sprouting stages. Different letters on each factor indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.

The interaction between cultivars and sprouting stages was statistically significant and influenced the starch accumulation pattern (Figure 5). The highest starch content was recorded in Crozo at the 2 cm sprouting stage (22.53%), followed by Hermes at 1 cm (22.46%), both significantly higher than all other treatment combinations. The lowest starch content was observed in Lady Rosetta at 1 cm (14.53%), differing significantly from all others.

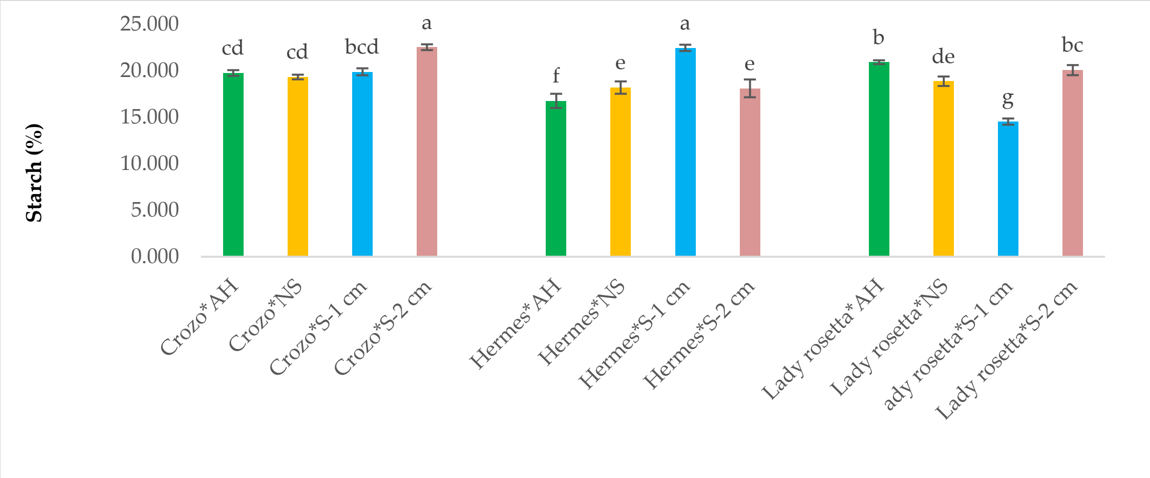

Figure 5: Interaction between cultivars and sprouting stages on starch content. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.
AH: At harvest, NS: Non-sprout, S: Sprouts

3.4. Total Sugar

Total sugar content varied significantly among the three potato cultivars (Figure 6). Crozo exhibited the highest total sugar percentage (0.17%), which was significantly higher than that Hermes (0.12%) and Lady Rosetta (0.11%), while the difference between Hermes and Lady Rosetta was statistically non-significant.

The total sugar content was monitored across four different stages: at harvest, non-sprouting, 1 cm sprout, and 2 cm sprout (Figure 6). The highest total sugar level was noted at harvest (0.21%), subsequently a significant reduction at the non-sprouting stage (0.12%), and further decreased at 1 cm (0.11%). The lowest sugar content occurred at the 2 cm sprouting stage (0.08%), which was significantly different from all earlier stages.

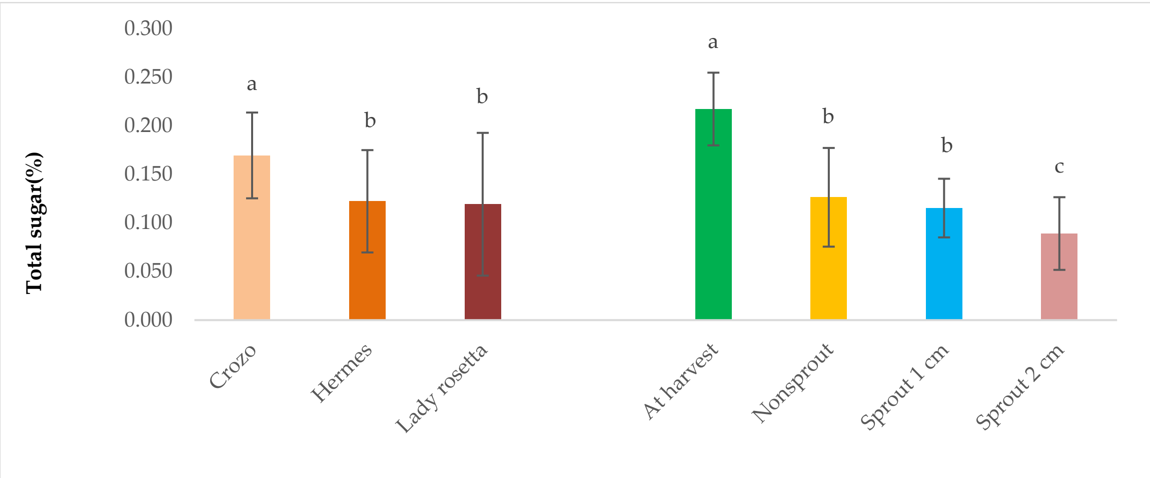

Figure 6: Total sugar (%) of potato cultivars and sprouting stages. Different letters on each factor indicate the presence of statistical differences at $p \leq 0.05$ level, as determined by the Duncan multiple range test.

The interaction between potato cultivar and sprouting stage markedly affected the total sugar content (Figure 7). Peak values were observed at harvest in Lady Rosetta (0.24%) and Crozo (0.23%), with no significant differences between them; they were significantly superior to the other treatments. The lowest total sugar levels were observed in Lady Rosetta at 2 cm (0.06%), Lady Rosetta at the non-sprouting stage (0.06%), and Hermes at 2 cm (0.06%), all of which were statistically similar and significantly lower than most of the other combinations.

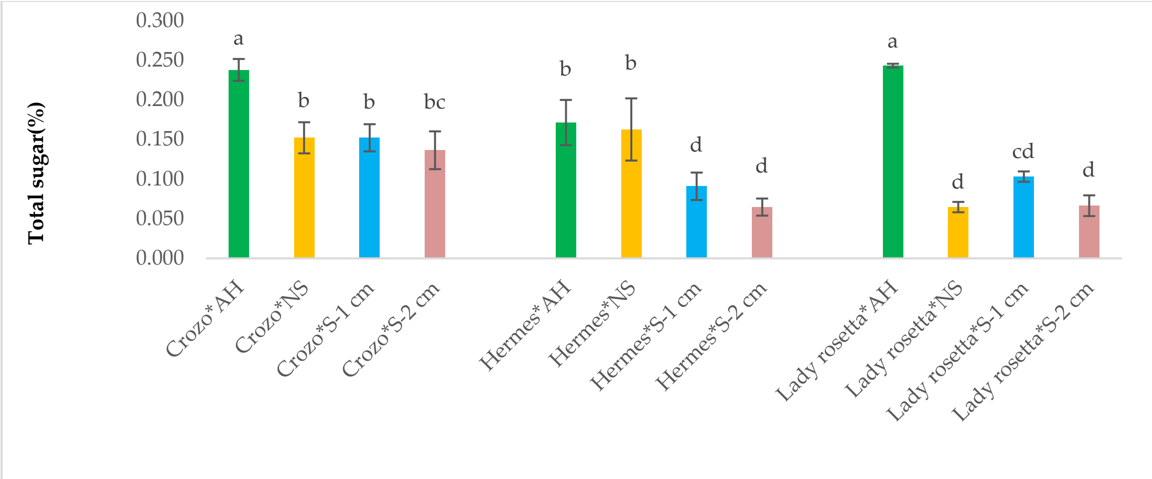

Figure 7: Interaction between cultivars and sprouting stages on total sugar. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test. AH: At harvest, NS: Non-sprout, S: Sprouts.

3.5. Total Soluble Solid

TSS consists of organic acids, amino acids, and soluble pectin, with the major content being the sugars. The TSS content of the tubers varied significantly among the studied cultivars (Figure 8). Lady Rosetta exhibited the highest TSS value (8.62%), followed by Crozo (6.85%) and Hermes (6.35%).
When examining TSS through sprouting stages (non-sprouted, 1 cm, and 2 cm), the results showed a consistent trend of significantly increased TSS in stored tubers compared with those evaluated at harvest (Figure 8). Non-sprouted tubers had the highest mean TSS (7.66%), followed closely by tubers with 1 cm (7.44%) and 2 cm (7.38%) sprout lengths, which showed no significant variation in TSS among the sprouted treatments. Tubers evaluated at harvest exhibited the lowest TSS (6.62%).

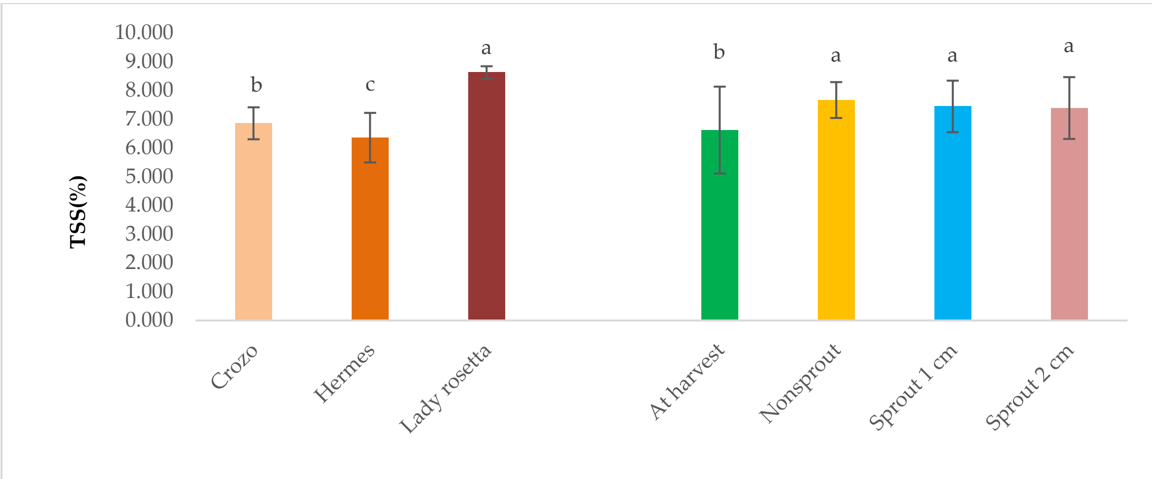

Figure 8: Total soluble solids of potato cultivars and sprouting stages. Different letters on each factor indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.

The interaction between cultivar and sprouting stage was statistically significant and revealed distinct patterns of TSS accumulation (Figure 9). The highest TSS values were recorded in Lady Rosetta at harvest and all sprouting stages, with the maximum value observed at 1 cm, 2 cm, and harvest stages (8.66%), which did not differ significantly from its non-sprouted condition (8.50%). These values were markedly higher than those recorded for other combination treatments. Intermediate TSS values were found in Crozo at the 2 cm sprouting stage (7.33%) and Hermes in the non-sprouted condition (7.33%), both of which differed significantly from lower-ranking interactions. The lowest TSS was observed in Hermes at the harvest stage (5.10%), which was significantly different from that of all other treatment combinations. These findings demonstrate that Lady Rosetta maintained consistently high TSS levels at all sprouting stages, whereas Crozo and Hermes exhibited more pronounced variability depending on the sprouting conditions.

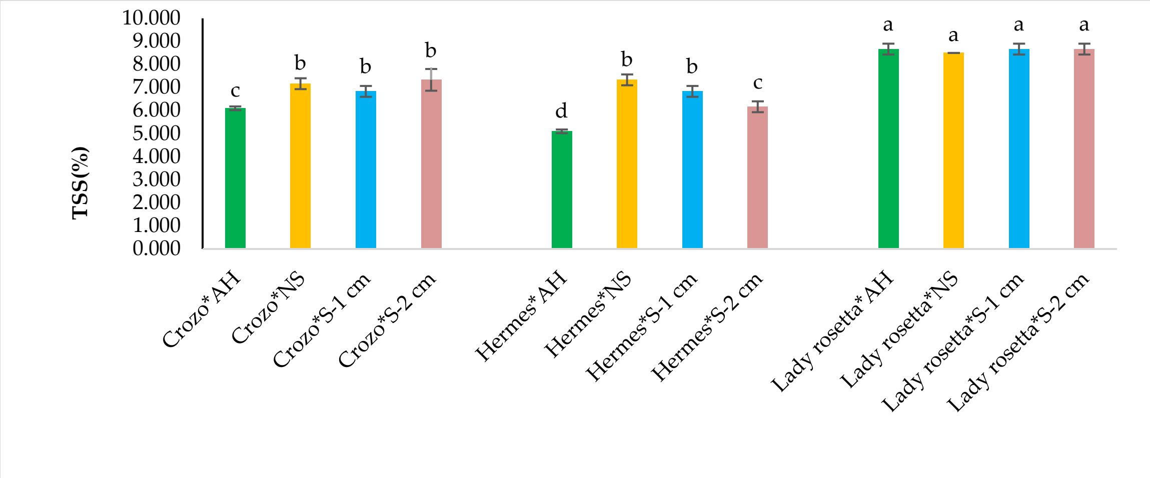

Figure 9: Interaction between cultivars and sprouting stages on TSS. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test. AH: At harvest, NS: Non-sprout, S: Sprouts

3.6. Hardness

The hardness (N) of the potato tubers varied slightly among the three studied cultivars: Lady Rosetta, Crozo, and Hermes (Figure 10). Lady Rosetta had the highest mean hardness (30.86 N), followed by Crozo (30.52 N) and Hermes (30.22 N). However, statistical analysis revealed no significant differences among the cultivars.

Hardness measurements were also taken at harvest, non-sprouted, and sprout lengths of 1 and 2 cm (Figure 10). The mean hardness at harvest was (31.70 N). This remained statistically unchanged at the 2 cm sprouting stage (31.47 N). However, a significant decline in hardness was observed at the 1 cm sprouting stage (29.82 N) and further decreased in the non-sprouted tubers (29.15 N), with no significant differences between them.

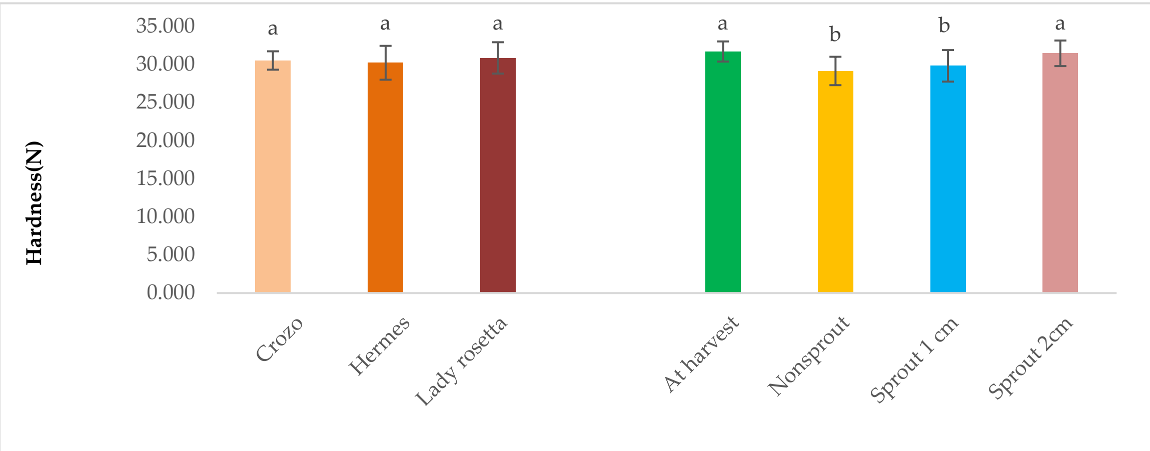

Figure 10: Hardness of potato cultivars and sprouting stages. Different letters on each factor indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.

The interaction between cultivar and sprouting stage was statistically significant (Figure 11). The highest value was observed in Lady Rosetta at harvest (33.02 N), which was significantly higher than most other combination treatments. In contrast, the lowest value was found in Hermes at the non-sprouted stage (27.29 N), which was significantly different from all other combinations.

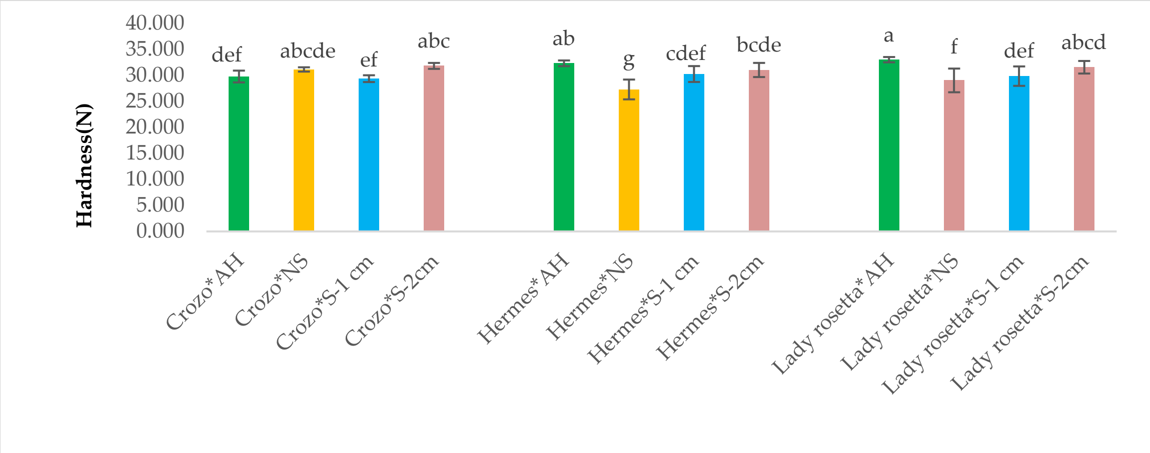

Figure 11: Interaction between cultivars and sprouting stages on hardness. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.
AH: At harvest, NS: Non-sprout, S: Sprouts

3.7. Sensory Evaluation of Potato Cultivar Chips

3.7.1. Chips Appearance

In this study, the sensory evaluation of chip appearance from three potato cultivars (Crozo, Hermes, and Lady Rosetta) showed no statistically significant differences. All cultivars exhibited high appearance scores when processed, with Crozo achieving the highest mean score (7.80), followed closely by Lady Rosetta (7.70), and Hermes (7.67) (Figure 12). These findings indicate that all three cultivars were visually acceptable and suitable for chip production. When examining the effects of harvest and sprouting stages, a clear trend was observed. Chips produced at harvest recorded the highest appearance score (8.33), which was significantly higher than all others, whereas scores gradually declined with sprout growth. The non-sprouted and 1 cm sprout stages both resulted in moderate appearance ratings (7.66), but the 2 cm sprouting stage showed a noticeable decline to a score of (7.23) (Figure 12).

Differences in chip appearance were further underscored by a significant interaction between cultivar and sprouting stage. Among the three cultivars, Crozo achieved the highest appearance score at harvest (8.60) and maintained relatively favorable values throughout the non-sprouted (7.90) and 1 cm sprouting (7.70) stages. However, its appearance declined markedly at the 2 cm sprouting stage (7.00), which represented the lowest score recorded among all treatments. Hermes also showed a noticeable decrease from the harvest (8.30) to the non-sprouted stage (7.30), followed by a slight recovery at 1 cm (7.50) and 2 cm (7.60). In contrast, Lady Rosetta maintained stable appearance scores from harvest (8.10) through the non-sprouted and 1 cm stages (both 7.80) but declined to (7.10) at the 2 cm stage (Table 1).

3.7.2. Chips Texture

In the evaluation of chips made from Lady Rosetta, tubers exhibited the highest texture score (7.67), followed by Crozo (7.57), and Hermes (7.15) (Figure 12). Although the differences were statistically significant, all cultivar chips were rated as moderately acceptable to good. The lower score for Hermes suggests a slightly less favorable crispness or bite when compared to the other two cultivars.

The measurement stages (harvest and sprouting) had a noticeable effect on chip texture. Chips produced from tubers at harvest recorded the highest overall texture score (8.00), whereas those from the 1 cm sprout stage showed a moderate decline (7.50). Further reductions were observed in chips from non-sprouted (7.26) and 2 cm sprouted tubers (7.10) (Figure 12).

The interaction between cultivars and sprouting stages was statistically significant for the texture of the chips, revealing differential responses among cultivars and sprouting stages. Crozo achieved the highest score at harvest (8.10) and maintained a relatively good texture through the 1 cm sprout stage (7.90). Hermes and Lady Rosetta's scores showed a gradual decline during the sprouting stages from harvest to 2 cm sprout (Table 1).

3.7.3. Chips Color

In the present study, the sensory evaluation of chip color from three potato cultivars (Crozo, Hermes, and Lady Rosetta) showed no statistically significant differences. The Lady Rosetta cultivar exhibiting (7.70) and Crozo (7.60) respectively, with slightly higher scores than Hermes (7.45) (Figure 12).

When considering the impact of harvest and sprouting stages on chip color, a clear trend emerged. At harvest, it exhibited the lightest and most desirable color, with scores averaging (8.33). However, as sprout growth increased, a noticeable decline in color intensity was observed. Chips from the non-sprouted and 1 cm sprout stages displayed moderate reductions in color, with scores of (7.63) and (7.43), respectively. The most significant decline in color occurred at the 2 cm sprout stage, where the chip color score dropped to (6.93), indicating a darker and less appealing appearance (Figure 12).

The interaction between cultivars and sprouting stages emphasizes significant variability in color scores. Generally, chips produced from all cultivars at harvest maintained relatively higher color scores than those produced in the sprouting stages. At the same time, Crozo and Lady Rosetta maintained relatively higher color scores, especially at the non-sprout stage, which gradually declined with sprout growth. Although Hermes recorded one of the lowest scores (6.80) at the non-sprout stage, the overall lowest score was observed in Crozo (6.50) at the 2 cm sprout stage, underscoring the detrimental effect of advanced sprouting on chip color across all cultivars (Figure 12).

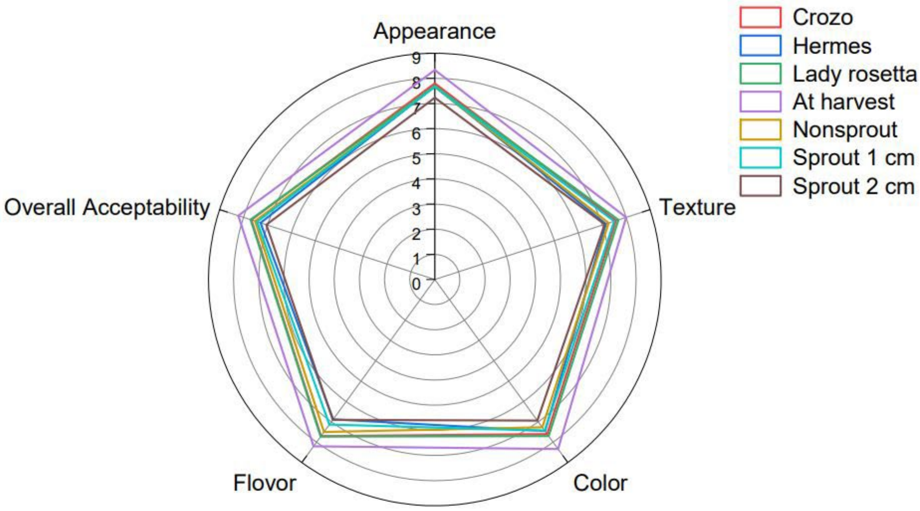

Figure 12: Radar chart showing the sensory evaluation of potato cultivar chips and sprouting stages.

3.7.4. Chips Flavor

In the present study, the sensory evaluation of chip flavors from three potato cultivars (Crozo, Hermes, and Lady Rosetta) showed significant differences. Lady Rosetta (7.72) and Crozo (7.70) had the highest flavor scores, indicating a well-balanced and desirable flavor profile. In contrast, Hermes (6.87) recorded a significantly lower score, suggesting that its flavor was less favorable than that of the other two cultivars (Figure 12).

When considering the impact of harvest and sprouting stages on chip flavor, a clear trend emerged. Potato chips at harvest recorded the highest flavor scores, averaging (8.20), indicating the best flavor quality. However, as storage progressed and sprout growth increased, a gradual decline in flavor was observed. Chips from the non-sprouted and 1 cm sprout stages showed moderate reductions in flavor, with scores of (7.50) and (7.13), respectively. The most significant decrease in flavor occurred at the 2 cm sprout stage, where flavor scores dropped to (6.90), reflecting a less desirable flavor profile than the other treatments (Figure 12).

The interaction between cultivars and sprouting stages emphasizes the significant variability in flavor scores. The maximum scores of flavor were obtained in all studied cultivars at harvest, reaching 8.60, 8.10, and 7.90 in Lady Rosetta, Crozo, and Hermes, respectively, and then gradually decreased throughout the sprouting stages. Additionally, no significant differences were found between other interaction treatments (cultivars and sprouting stages), except for the interaction between the 2 cm sprout in the Hermes cultivar, which exhibited the lowest scores (6.00) of flavor. These findings highlight that although all cultivars experienced some flavor deterioration with storage and sprouting, Hermes was the most sensitive, whereas Lady Rosetta and Crozo maintained a better flavor under extended storage conditions and sprouting stages (Table 1).

3.7.5. Overall Acceptability

The overall acceptability evaluation of potato chips produced from three potato cultivars (Crozo, Lady Rosetta, and Hermes) at different sprouting stages revealed significant differences influenced by both cultivars and sprouting stages. The overall acceptability scores showed a clear declining trend in chip quality with increasing sprout growth. The results in figure 12 demonstrate that the highest overall acceptability scores were not statistically significant in the Crozo (8.27) and Lady Rosetta (8.22) cultivars, which outperformed the Hermes (8.15). Generally, all three cultivars were highly suitable for chip production. Regarding the impact of sprouting stages in figure 12 , it appears that the chip scores significantly decreased with sprouting growth. However, the best scores were obtained for chips produced at the harvest stage, which was significantly better than that of the sprouting stages. The lowest overall chip acceptability scores were observed for the 2 cm sprouting.

At harvest, all cultivars demonstrated the highest overall sensory scores, with Crozo (8.27) having slightly higher scores than Lady Rosetta (8.22) and Hermes (8.15). These differences were not statistically significant, indicating that, under fresh conditions, all three cultivars were highly suitable for chip production. As storage progressed, a significant decline in the overall chip quality was observed, particularly as sprout development advanced. Chips produced from non-sprouted tubers showed moderate reductions in sensory scores compared to fresh samples, with Crozo (7.62), Lady Rosetta (7.87), and Hermes (7.05) scoring. More pronounced reductions were observed at the 1 cm sprouting stage, where scores dropped to (7.62) for Crozo, (7.52, and) for Crozo, Lady Rosetta, and (7.15) for Hermes, respectively. At the 2 cm sprouting stage, the lowest sensory scores were recorded: (7.15) for Crozo, (7.17) for Lady Rosetta, and (6.80) for Hermes (Table 1).

Table 1: Interaction impact between cultivars and sprouting stages on chips sensory evaluation.

Cultivars	Sprouting Stages	Appearance	Color	Texture	Flavor	Overall Acceptability
Crozo	At harvest	8.60 a ± 0.49	8.30 ab ± 0.78	8.10 a ± 0.53	8.10 ab ± 1.04	8.27 a ± 0.36
	Non-sprout	7.90 abcd ± 0.83	8.20 abc ± 1.16	6.70 cd ± 1.10	7.70 abcd ± 1.18	7.62 bc ± 0.37
	Sprout 1 cm	7.70 bcde ± 1.10	7.40 bcdef ± 1.35	7.90 ab ± 1.22	7.50 bcd ± 1.11	7.62 bc ± 0.63
	Sprout 2 cm	7.00 e ± 0.63	6.50 f ± 0.80	7.60 abcd ± 1.20	7.50 bcd ± 1.20	7.15 cde ± 0.61
Hermes	At harvest	8.30 ab ± 0.64	8.50 a ± 0.67	7.90 ab ± 0.70	7.90 abc ± 0.70	8.15 a ± 0.35
	Non-sprout	7.30 cde ± 0.64	6.80 ef ± 0.74	7.20 abcd ± 0.60	6.90 cde ± 1.04	7.05 de ± 0.47
	Sprout 1 cm	7.50 bcde ± 0.80	7.50 bcde ± 0.50	6.90 bcd ± 0.70	6.70 de ± 1.00	7.15 cde ± 0.49
	Sprout 2 cm	7.60 bcde ± 0.49	7.00def ± 0.77	6.60 d ± 0.66	6.00e ± 1.24	6.80 e ± 0.41
Lady Rosetta	At harvest	8.10 abc ± 0.63	8.20 abc ± 0.60	8.00 a ± 0.77	8.60 a ± 0.49	8.22 a ± 0.37
	Non-sprout	7.80 bcde ± 0.87	7.90 abcd ± 0.94	7.90 ab ± 0.83	7.90 abc ± 1.13	7.87 ab ± 0.35
	Sprout 1 cm	7.80 bcde ± 0.60	7.40 bcdef ± 1.01	7.70 abc ± 1.26	7.20 bcd ± 0.74	7.52 bcd ± 0.50
	Sprout 2 cm	7.10 de ± 0.94	7.30 cdef ± 1.00	7.10 abcd ± 1.37	7.20 bcd ± 0.97	7.17 cde ± 0.60

* Scores in the same column with different letters are statistically different at $p \le 0.05$, as determined by Duncan's multiple range test. Each data point represents the mean of ten sample replicates ± standard deviation.

3.8. Overall Acceptability Comparison Among Market Potato Chips and Cultivars Studied

A comparative analysis was performed using three popular commercial chip brands (labeled A, B, and C) to assess the sensory quality of chips produced from the three potato cultivars (Lady Rosetta, Crozo, and Hermes). Sensory evaluation scores revealed statistically significant differences among the samples (Figure 13). Lady Rosetta chips received the highest average score (7.87), followed by Crozo chips (7.62). These scores were significantly higher than those of the commercial brands and Hermes chips.

Commercial brands A and B, with average scores of 7.35 and 7.27, respectively, fell within the mid-range of acceptability. Although their scores were statistically lower than those of Lady Rosetta and Crozo, they were significantly higher than those of Hermes and Brand C. Brand C and Hermes chips received the lowest scores (7.07 and 7.05, respectively), with no significant difference between them.

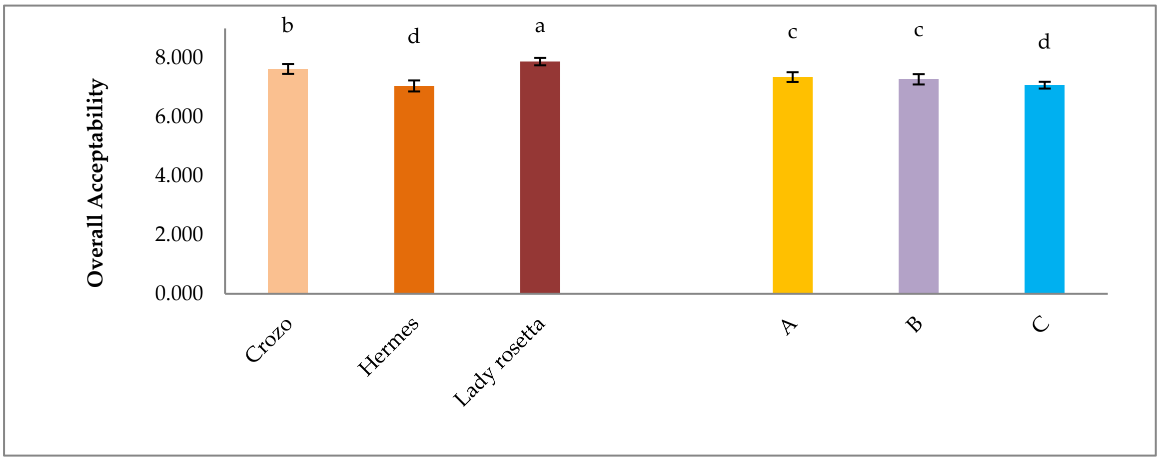

Figure 13: Overall acceptability of chips from studied potato cultivars, and A, B, and C represent three commercially available potato chip products. Different letters indicate the presence of statistical differences at $p \leq 0.05$, as determined by the Duncan multiple range test.

4. Discussion

Weight loss during storage is primarily driven by physiological processes such as moisture evaporation and respiration, both of which are influenced by cultivar-specific characteristics, including skin thickness, tuber surface area, and metabolic activity [31]. Weight loss from sprouting and decay of tubers during on farm storage has been estimated to range from 10% to 40%, depending on factors such as storage duration, method, and location, as well as the variety and maturity of the tubers, and the level of protection against sunlight, heat, and rain [32]. These findings suggest that Lady Rosetta has superior storage stability in terms of minimizing weight loss, which may be attributed to its lower rate of water loss through respiration and transpiration [33]. The lower weight loss observed in Lady Rosetta may reflect a more dormant physiological state or a tighter skin barrier, which helps to reduce water loss [34]. Conversely, the higher values in Crozo and Hermes may indicate more active metabolic processes or greater susceptibility to dehydration under given storage conditions [35]. Apart from location and season, another important factor contributing to this discrepancy is pre-harvest agronomic practices such as irrigation schedules, fertilizer application, and harvest timing [36, 37]. These practices directly affect tuber physiology at harvest by influencing parameters such as tuber maturity, skin development, and water content, all of which have downstream effects on post-harvest weight loss [38]. For instance, tubers harvested prematurely or under high soil moisture conditions may be more prone to water loss during storage because of their thinner or less mature periderm layer [37].

Regarding the dry matter content, statistical analysis showed that Crozo differed significantly from both Hermes and Lady Rosetta, whereas no significant difference was detected between the last two cultivars. In contrast, Amjad *et al.* [39] reported lower dry matter contents for the same cultivars: Crozo (21.79 ± 2.21%), Hermes (26.88 ± 1.65%), and Lady Rosetta (27.17 ± 2.25%). Compared to their findings, the dry matter level of Crozo was considerably higher in the current study, whereas those of Hermes and Lady Rosetta were slightly lower. This discrepancy may be attributed to several agronomic factors, particularly fertilization practices. High nitrogen fertilization has been reported to delay tuber maturation, thereby reducing dry matter accumulation [40, 41]. In addition, excessive irrigation can dilute the dry matter content owing to increased water uptake by the tubers, especially when overwatering occurs close to harvest [42]. Planting time may also play a role, as environmental conditions (temperature, rainfall, and day length) during key growth stages affect starch synthesis and dry matter deposition [43]. These differences may be attributed to weight loss in the tubers during storage caused by the concentration of the tuber solution, as illustrated in figure 1, where the lowest weight loss to the highest appeared in the Lady Rosetta, Hermes, and Crozo tubers, respectively. Statistical analysis revealed that the 2 cm sprouting stage was significantly different from the non-sprouted stage, while the “at harvest” and “1 cm” stages indicated partial but non-significant differences. These results align with the findings of Liu *et al*. [44], who noted that the dry matter content may increase in certain parts of the tuber during the early stages of sprouting. Their study showed that sprouting tubers exhibited upregulated expression of genes related to starch degradation and resynthesis, reflecting active carbohydrate mobilization. Such metabolic activity, which supports the initiation of sprout growth, can temporarily concentrate the dry matter content in the tuber. The peak observed in the current study at the 2 cm sprouting stage aligns with this physiological mechanism, suggesting that early sprouting involves dynamic internal changes that elevate dry matter through localized starch metabolism. This activity supports sprout initiation and can elevate the dry matter content through localized carbohydrate mobilization [45]. The intermediate values at the “at harvest” and “1 cm” stages likely represent a transition period during which metabolic changes emerge but are not yet fully active. In contrast, the lowest value recorded in non-sprouted tubers indicates a more metabolically dormant state, where starch reserves remain stable owing to the recent cessation of photosynthetic supply from the mother plant. These results were reinforced by Liu *et al.* [44], who documented increased expression of genes related to starch degradation and resynthesis in sprouting tubers. Their study also emphasized that tubers harvested from green vines continue to receive assimilates from the mother plant, whereas sprouting tubers rely solely on internal reserves, resulting in distinct metabolic profiles across the developmental stages.

Conversely, variations in starch content among potato cultivars are affected by genetic makeup, environmental factors, carbohydrate metabolism, hormonal control, and developmental stages [45]. Additionally, this may be attributed to the dry matter content in the potato tubers, as illustrated in figure 2, where the highest dry matter content was found in Crozo, while the lowest was found in the Lady Rosetta tubers. Furthermore, delayed starch degradation in certain cultivars or under specific storage conditions, such as moderate temperatures and controlled humidity, may postpone enzymatic activity, allowing starch levels to remain stable or temporarily increase before significant breakdown occurs [46]. Compared to the findings of a study carried out in Faisalabad, Pakistan, notable differences in starch content were evident [39]. In that study, Crozo recorded a starch content of 14.82 ± 2.47%, Hermes 15.77 ± 2.38%, and Lady Rosetta 18.01 ± 2.11%. Following storage at 11 °C, starch levels increased across all cultivars, reaching 19.36 ± 0.81% in Crozo, 23.51 ± 1.01% in Hermes, and 23.02 ± 1.07% in Lady Rosetta. These comparisons revealed a divergent trend for Crozo and Hermes, both of which exhibited lower starch content in the Faisalabad study than in the present study. In contrast, Lady Rosetta demonstrated relatively consistent starch levels across both studies, indicating potential stability in its starch accumulation capacity under varying environmental and storage conditions.

Additionally, the current results finding contrasts with the commonly observed trend of decreasing starch content during sprouting, which is typically driven by enzymatic activity, mainly amylases and phosphorylases that convert starch into sugars to support sprout growth [12, 45, 47]. The increase in starch content noted in this study could be attributed to moisture loss during storage, as water loss through transpiration and respiration can concentrate dry matter components, including starch, leading to an apparent increase in dry weight [48]. Because starch percentage is directly derived from dry matter, the proportional relationship between them explains why cultivars with higher dry matter (e.g., Crozo and Lady Rosetta) also exhibit higher starch levels, contributing to firmer texture, lighter chip color, reduced oil uptake, and increased crispiness during frying [20, 49, 50].

Furthermore, the results of the current study reflect cultivar-specific differences in carbohydrate accumulation and suggest that Crozo may inherently store more sugars at physiological maturity, which could affect its processing quality, particularly in frying operations, owing to potential darkening caused by the Maillard reaction [51, 52]. When compared to published values measured before storage, the same cultivars displayed slightly lower total sugar levels: Lady Rosetta (0.11%), Hermes (0.10%), and Crozo (0.10%) [53]. Despite minor differences in the absolute values, the ranking order of sugar accumulation was notably different. These discrepancies may arise from differences in experimental conditions, maturity at harvest, environmental stress, or analytical methods [52, 54]. Nonetheless, both datasets confirm that inter-cultivar differences in sugar levels exist at harvest, which are important to consider when selecting potato varieties for storage or industrial applications. In the current study, the observed decrease may indicate that sugars were actively consumed to support the metabolic requirements of sprout growth [55]. Additionally, sugar accumulation is minimal at 8–12 °C, making potatoes suitable for processing; however, this temperature range also promotes sprout growth [56]. When comparing these findings with published data for the same cultivars stored at 11°C, a different pattern emerges. The reported total sugar content after storage was 0.21% for Hermes, 0.19% for Lady Rosetta, and 0.18% for Crozo, indicating a consistent increase in sugar concentration post-storage across all varieties [16]. The contrast between the current results declining during sprouting and the published post-storage increases in total sugar may be explained by the different storage durations, sampling points, and soil temperatures [46, 52].

The current findings demonstrate that Lady Rosetta maintained consistently high TSS levels at all sprouting stages, whereas Crozo and Hermes exhibited more pronounced variability depending on the sprouting conditions. The current results indicate a clear cultivar-dependent difference in the TSS accumulation. When compared to earlier studies, Hermes was previously reported with a TSS of (5.62 ± 1.19 °Brix), and Lady Rosetta with (5.55 ± 1.49 °Brix) in one study [57], while another study recorded (5.56 ± 1.49 °Brix) for Lady Rosetta [58]. Methodological differences in TSS determination, such as the use of a hand-Refractometer in the current study, may also explain the discrepancies when compared to earlier research that may have been measured by a digital refractometer [59]. The higher TSS values obtained in the current study could be attributed to favorable environmental and agronomic conditions, such as soil quality, fertilization, and irrigation practices, which can enhance carbohydrate metabolism [60]. Additionally, genetic variability within cultivars, differences in seed tuber origin, and harvest maturity may contribute to the observed variation in TSS levels [61]. Storage significantly influenced the TSS values in potato tubers.

The observed increase in TSS with sprouting stages compared to harvest may be due to the enzymatic breakdown of starch into simpler soluble sugars during the physiological transition from dormancy to active growth [62]. This metabolic shift reflects the tuber's preparation to support sprout development by increasing soluble carbohydrates, such as glucose and fructose [63]. These findings are in agreement with those of previous studies. Several studies have confirmed that storage at different temperatures initiates the conversion of starch into soluble sugars, such as glucose and fructose, contributing to an increase in TSS [64]. For example, Mostofa *et al.* [65] reported a rising trend in TSS during the storage of potatoes, while similar research showed increased sugar levels following dormancy release and early sprouting stages. Di *et al.* [45] emphasized that during the shift from dormancy to sprouting, potato tubers undergo significant metabolic changes, converting starch into soluble carbohydrates to support sprout growth.

Softening of potatoes starts early during storage, even before sprouts appear, and becomes stronger as sprouting begins [66]. The increase in hardness at harvest and the 2 cm sprouting stage may be due to the tubers of these treatments having peak dry matter and starch levels, as shown in figures 2 and 4, which causes the cell wall structure to be stronger. The decline in hardness of non-sprout and 1 cm sprout is likely due to physiological and biochemical changes, such as water loss, enzymatic degradation of starch, and weakening of cell wall structure [33]. These changes reduce the tissue turgidity and structural integrity, contributing to the decreased mechanical resistance of the tubers. Similar trends have been reported in previous studies, where respiration and metabolic activity during early sprouting stages were linked to increased tissue softening [67]. Compared to earlier work, the current findings show intermediate hardness values, which are higher than those reported in some studies, but lower than others. For instance, a previous study reported hardness values of (13.58 N) and (13.54 N) for the 'Atlantic' and 'Solbong' cultivars, respectively, following 12 weeks of storage at 10 °C (202). In contrast, our non-sprouted tubers maintained a hardness of (29.15 N) after storage conditions (10 °C). Our data showed only an 8% reduction in hardness over 12 weeks, whereas in the cited study, hardness levels were less than half of our, indicating substantial varietal differences in structural retention. Further supporting this contrast, another study reported a linear decrease in hardness during storage, with the 'Atlantic' cultivar losing (0.99 N) per day, while the 'Ágata' cultivar showed a milder decline of (0.33 N) per day [17]. These differences underscore the importance of cultivar-specific traits in hardness retention. The relatively high hardness in our study is likely due to slower sprouting, reduced water loss, and cultivar-specific starch composition and cell wall strength, which confer resistance to softening during storage [32]. Conversely, a separate investigation reported higher initial hardness values across six potato cultivars: K. Bahar (183 N), K. Ashoka (104 N), K. Kanchan (92 N), K. Kunden (154 N), K. Dewa (187 N), and K. Lalima (127 N). These values exceed those recorded in our study, possibly because of cultivar genetics, earlier measurement time post-harvest, or differing physiological maturity and storage factors [66, 68]. Despite this, the overall pattern across all studies consistently highlights the influence of varietal characteristics on firmness retention [68].

Concerning the Sensory evaluation of potato chips, this decline in the appearance of potato chips is attributed to biochemical changes, such as starch degradation, sugar accumulation during sprouting, and an increase in the TSS in these tubers, which can lead to darker and less desirable chips upon frying [16]. These results suggest that extended sprouting, particularly beyond 1 cm, negatively influences the visual quality of tubers, with variations in the degree of impact depending on the cultivar. These findings indicate that chip appearance is optimal when tubers are processed soon after harvest or when sprouting becomes visible.

The current results indicate that, as storage and sprouting progress, the texture quality of potato chips tends to decline. This trend may be attributed to biochemical changes such as starch degradation, an increase in the TSS during sprouting stages, and increased moisture mobility during storage, which can negatively influence the crispness of the fried product [69]. These findings suggest that both Crozo and Lady Rosetta have better texture stability in the sprouting stage, whereas Hermes are more sensitive to changes induced by sprouting.

The current findings indicate that all three cultivars produced chips with a comparable golden-brown hue, which meets typical consumer expectations. This decrease in the color score of chips is likely due to chemical changes associated with sprouting, such as the breakdown of starches and accumulation of reducing sugars, which can lead to darker chips upon frying [70, 71].

These findings suggest that Lady Rosetta and Crozo produce chips with a more appealing flavor than Hermes. This trend aligns with previous research highlighting flavor as a primary factor in the consumer acceptance of potato chips. A study comparing industrial and composite potato chips reported similar variations in sensory attributes across different chip types, attributing flavor differences to the composition of volatile compounds, such as aldehydes, ketones, esters, and alcohols. Notably, the higher flavor ratings for fresh-cut fried chips in the literature support our observation that chips made from cultivars with better inherent quality yield more favorable sensory outcomes. These findings imply that cultivar selection is a key factor in chip flavor even prior to processing and should be considered a foundational step in quality-oriented chip production. Further analysis of the volatile compound profiles in these cultivars could provide deeper insights into the biochemical basis of their flavor differences [72].

The results indicated that with sprouting progress, chips significantly decreased flavor scores. Sprouting leads to increased respiration and changes in the stored compounds in potato tubers, particularly starches and proteins, resulting in higher sugar concentrations owing to starch hydrolysis. These physiological and biochemical changes negatively affect the nutritional quality and overall condition of potatoes, including their processing quality and flavor profile. The accumulation of sugars and other compounds during sprouting can contribute to off-flavors and reduce chip quality [32].

The overall acceptability scores, which included the average of all appearances, textures, colors, and flavors, showed a clear trend of declining chip quality with increasing sprout growth. These observations are consistent with those reported by Parving *et al*. [6], who observed that prolonged storage and sprouting significantly reduced the sensory acceptability of potato chips owing to increased sugar accumulation and associated changes in frying behavior. The high sensory scores recorded at harvest can be attributed to the favorable physicochemical characteristics of fresh tubers, such as high starch content, low reducing sugars, and firm texture, which contribute to a golden color, crispy bite, and desirable flavor of the final chips [40].

The moderate reduction in scores for chips from non-sprouted tubers reflects early physiological changes during storage, such as moisture redistribution and limited starch breakdown, which may affect texture and flavor, although not yet severely affect visual appeal [63]. As sprouting progresses to the 1 cm and 2 cm stages, a more pronounced deterioration in sensory attributes is evident, driven by sprouting-induced biochemical changes. These include starch hydrolysis, sugar accumulation, and increased respiration, which intensify the Maillard reactions during frying, resulting in darker coloration, tougher textures, and off-flavors that reduce consumer acceptance [6, 63].

These findings suggest that Lady Rosetta and Crozo may offer a slight advantage in preserving chip quality, while demonstrating strong overall stability across all conditions. These cultivar-specific differences are consistent with previous studies showing that the cultivar strongly influences the extent of chemical changes in stored potato tubers [73].

As for comparison among market potato chips and cultivars studied, the superior performance of Lady Rosetta and Crozo could be due to their elevated dry matter and starch levels, which are known to improve chip crispness and reduce oil absorption during frying, both key attributes influencing consumer preference. Additionally, these cultivars likely produced a more uniform golden color and desirable texture owing to lower sugar accumulation, reducing the Maillard reaction, which may cause excessive browning and undesirable flavors [74]. Brands A and B, with moderate scores, indicate that some commercial products can maintain moderate quality, although variability in raw material origin, storage, and processing conditions might influence their performance [75]. The lower acceptability of Hermes chips could be linked to a combination of lower dry matter content and higher sugar concentration, which negatively affects texture and color uniformity [76]. Similar sensory drawbacks in Brand C may reflect the use of non-optimal raw materials or less-controlled processing conditions [75, 76].

Overall, the relationships observed among the chemical, physical, and sensory parameters highlight the complex influence of the sprouting stage and cultivar on chip quality. Higher dry matter and starch contents are generally associated with superior firmness and more desirable chip color and texture, whereas elevated sugar and TSS levels promote darker coloration and reduced flavor acceptability [20]. These chemical shifts during sprouting are reflected in physical properties such as weight loss and hardness, which in turn influence the sensory profile of the chips [77]. Cultivar-specific responses further emphasized that Lady Rosetta and Crozo maintained better chemical stability and sensory acceptability during sprouting than Hermes [72]. Thus, the interaction of cultivar traits with sprouting physiology determines not only the storage stability of tubers but also the final consumer-oriented quality of chips, underlining the importance of integrated evaluation for industrial processing. From a practical perspective, these findings highlight the importance of selecting cultivars with higher dry matter and lower sugar accumulation (e.g., Lady Rosetta and Crozo) and limiting storage duration to the early sprouting stages to preserve chip quality, which can guide both industrial processing practices and breeding strategies.

5. Conclusions

This study found significant differences among cultivars and sprouting stages for all the measured parameters. At harvest, showed more acceptable processing potential for chip, with Crozo and Lady Rosetta demonstrating favorable dry matter and starch content, along with high sensory scores for chip appearance, texture, color, and flavor. In particular, Crozo and Lady Rosetta have emerged as promising cultivars for chip processing under the storage conditions common in the Kurdistan Region. Although Lady Rosetta had the longest storage period (125 days) to start sprouting, it showed greater weight retention, and Crozo maintained a high starch content across all stages studied. In addition, both cultivars were significantly superior to the chip market brands in terms of overall acceptability. Future studies should include additional cultivars and variable growing environments to improve generalizability. Further research should also focus on enzymatic activity, sugar and starch metabolism, and gene expression related to sprouting and glycoalkaloid accumulation, as well as on developing optimized storage and processing strategies to maintain chip quality and consumer safety.

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