

Evaluation of the nutritional and functional properties during processing of edible drink in the highlands of Ecuador

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Abstract

Maize (*Zea mays*) serves as a key staple crop in Ecuador's high-altitude regions, yet its full nutritional and functional potential remains underexplored. To address this, the present study evaluated five improved maize varieties developed by the Instituto Nacional de Investigaciones Agropecuarias (INIAP) Ecuador, focusing on changes in carbohydrate composition, antioxidant activity, and bioactive compounds across three processing stages: raw, germinated, and fermented. Significant varietal differences were observed in physical characteristics and functional compound profiles. Germination enhanced total polyphenol content and antioxidant activity in all varieties, likely due to increased biosynthesis and improved extractability. Fermentation generally reduced antioxidant activity, although INIAP 199 retained high polyphenol levels post-fermentation. Sensory evaluation showed a strong preference for the dark-colored INIAP 199, which also exhibited the highest antioxidant compound levels. These findings highlight the importance of variety-specific processing strategies to preserve functional components and support the development of value-added maize products. Such approaches could contribute to improved nutrition and economic opportunities for smallholder farmers. Further research should assess bioavailability and environmental influences to inform practical applications in functional food development.

1. Introduction

Maize (*Zea mays*), plant of the *Poaceae* family, is believed to have been domesticated from wild grasses by Indigenous peoples in Mexico approximately 7,000 years ago. Alongside rice and wheat, it is one of the most widely consumed staple crops globally, serving as a primary food source for both humans and livestock [1]. Maize is composed of approximately 72% starch, 4% lipids, and 10% protein, along with essential minerals and vitamins. Additionally, depending on its pigmentation, maize contains various antioxidant compounds, such as anthocyanins, flavonoids, and carotenoids, that have been widely recognized for their potential role in preventing respiratory diseases, cardiovascular conditions, and certain cancers [2, 3].

Approximately 30% of Ecuador's total maize production occurs in high-altitude regions. However, maize cultivation in such environments presents significant agronomic challenges due to extreme climatic conditions. At elevations exceeding 3,000 meters, crops are frequently exposed to drought induced by high temperatures, unpredictable precipitation patterns, hail, and frost, all of which negatively impact maize growth and yield stability. To address these challenges, the Instituto Nacional de Investigaciones Agropecuarias (INIAP), Ecuador has developed improved maize varieties by selectively breeding landraces adapted to specific regional conditions. This breeding initiative enhances the adaptability of maize to high-altitude environments while also playing a crucial role in preserving the crop's genetic diversity, thereby contributing to sustainable agricultural development in Ecuador [4].

This study focuses on five improved maize varieties developed by INIAP, which are currently cultivated in Ecuador's high-altitude regions. These varieties exhibit distinct morphological and physiological traits

that contribute to their adaptability and agronomic performance. INIAP 101 is a white, large-kernel maize with a floury texture and strong resistance to pests and diseases [5]. INIAP 122 is a yellow floury maize variety characterized by early growth, short plant height, resistance to lodging and ear rot, and high grain quality [6]. INIAP 199 has a black-to-purple coloration with a floury texture and is distinguished by its high yield potential [7]. INIAP 180 has a crystal yellow kernel type and exhibits strong disease resistance [8]. INIAP 193 possesses wrinkled yellow kernels that develop a crispy texture when roasted and dried, making them suitable for use in snacks and beverages [9]. Despite their widespread cultivation, the functional properties of these varieties remain largely unexplored.

By other hand, in high-altitude regions of Ecuador, maize is consumed in various forms, including fresh, toasted, milled and cooked, or further processed into products such as fermented beverages “*Chicha*”, corn chips, and cereals. Among them, is *Chicha*, a traditional fermented beverage widely consumed across South America, particularly in Ecuador and Peru [10]. This beverage was used both as part of daily diet of the Inca population and as an essential element during the political and religious ceremonies [11].

Chicha is made with germinated corn grains; the time of fermentation can vary. It can be hours or even days. These differences may influence the sensorial characteristics of *Chicha* such as the flavor and the chemical and bioactive composition along with the microbiome profile after fermentation, the addition of spices or sugar, among other factors. Some microorganisms may participate in parallel, while others act in a sequential manner with a changing dominant flora during the course of the fermentation [12]. It contains beneficial lactic acid bacteria such as *Lactobacillus plantarum*, *Lactobacillus fermentum*, and *Weissella cibaria*, which are associated with various health benefits [11, 13].

Also, the fungi genera *spargillus*, *Paecilomyces*, *Cladosporium*, *Fusarium*, *Penicillium* and *Trichothecium* are the most frequently found in certain products. The common fermenting yeasts are species of *Saccharomyces*, which results in alcoholic fermentation. Natural fermentation of cereals leads to a decrease in the level of carbohydrates as well as some non-digestible poly and oligosaccharides. Certain amino acids may be synthesized and the availability of B group vitamins may be improved [12].

This study aimed to investigate the value-added potential of highland maize varieties developed for cultivation in Ecuador’s mountainous regions by evaluating changes in their nutritional and functional properties during germination and fermentation. These findings are expected to support the targeted production of maize varieties with desirable functional traits, improve processing efficiency, and inform the development of functional or health-oriented fermented products. Moreover, identifying varieties with high levels of bioactive compounds may enable their application as beverages, ingredients in health foods, functional food products, animal feed, or even in pharmaceutical and food processing industries, thereby contributing to new market opportunities for smallholder farmers and enhancing the economic value of local agricultural resources.

2. Materials and Methods

2.1 Raw material

Samples of five improved maize varieties were provided by “Programa de Maíz” (INIAP). These varieties were selected for the research based on the diverse types and colors of grains and farmers’ preferences (Table 1). Kernels of the maize varieties were harvested from the Estación Experimental Santa Catalina (INIAP) and farmers' locations in the province of Cotopaxi. For the preliminary characterization of raw samples, grains of each maize variety (approximately 250 grams) were ground using an Ultra-Zentrifugalmühle ZM 200 (Retsch, Haan, Germany), the samples were packed and sealed in polypropylene bags and stored at room temperature until use.

Table 1
Maize varieties used to evaluate changes in functional ingredients during processing

Maize variety	Color	Type of grain
INIAP 101	White	Flourly
INIAP 122	Yellow	Flourly
INIAP 199	Black/Purple	Flourly
INIAP 180	Yellow/Orange	Flint
INIAP 193	Yellow	Sweet

2.2 Sample preparation

For germination samples, the grains were immersed in water for 1–2 days, depending on the moisture content of each variety. Following this, the grains were removed from the water and drained. The samples were placed on a surface and they were covered with polypropylene plastic and germinated for 2–4 days at room temperature, then dried in a toaster oven (Barber-Colman, Rockford Illinois, USA), according to the following drying process: 35°C for 14 h, 45°C for 10 h, 55°C for 12h and after 65°C for 9 h. The samples were ground for further use.

For fermentation process, 200 mL of water was added to 14.81 g of germinated sample powder. The mixture was maintained at 40°C for 30 min, and heated at 70°C for 1 h with continuous stirring in a shaker (Micromat Co., Mahwah, New Jersey, USA), each sample were placed in fermentation containers and fermented for 2 days at room temperature. Part of the samples were dried in freeze-drying (LABCONCO, Kansas, USA) at -0.8 bar pressure and ground into a fine powder to measure functional compounds and total starch content; and the other part of kept in refrigeration (4 °C) for further analysis (sensory acceptability analysis). The process flow diagram is shown Fig. 1.

2.3 Analysis methods

2.3.1 Physical analysis

Grain size was used a Mitutoyo digital caliper (Mitutoyo, Sao Paulo, Brazil), to evaluate the width and length of the samples. Test weight (TW) and Thousand kernel weight (TKW) was determined by method 55-10.01 (AACC, 2010) [14] and expressed as kilograms per hectoliter. Thousand kernel weight was determined by weighing 1,000 kernels of a representative sample and recording the weight in grams. Colour measurements were performed using a portable spectrophotometer (Lange Spectro-Color d/8° model LZM 268, Chelmsford, UK) based on the CIEL*, a*, b* colour system. With each grain variety were performed 20 measurements. Change in food colour is measured in terms of change in L* (lightness), which ranges from 0 to 100, a* (red–green) and b* (blue–yellow) chromaticity coordinates, which range from – 120 to 120 coordinates are used for uniform distribution of colours as they have a very close relation to human perception of colour, C* (chromatism), and H* (hue).

2.3.2 Chemical analysis

The moisture content was determined according to standardized method AOAC (934.06). The total titratable acidity (947.05) was determined by titrating 10 mL of the sample with NaOH solution (0.1N) and expressed as % lactic acid, while pH (943.02) measurement with an 827 pH lab (Metrohm, Herisau, Switzerland), and soluble solids (932.12) were determined with Atago, Tokyo, Japan according to the methods AOAC [15]

Total starch content

Starch content was determined using enzymatic assay. A 50 mg of sample was mixed with a solution alkaline, neutralized to pH 4.75 and hydrolyzed with α -amylase (from *Bacillus licheniformis*, Type XII-A) at 60°C for 45 min. The supernatant diluted, and mixed with 2 mL of anthrone. The absorbance was measured at 605 nm using a PF-11 photometer (MACHEREY-NAGEL, North Rhine-Westphalia, Germany) [16].

Total sugar content

Total sugar content was determined after extraction with 80% ethanol solution. A aliquot of the diluted sample was mixed with 2 mL of anthrone. The absorbance was measured at 605 nm using a PF-11 photometer [17].

Assessment of Diastatic Power

Diastatic power was evaluated in raw and germination samples following enzymatic extraction with papain at room temperature for 18–22 h. This enzymatic activity was quantified by titration with sodium thiosulfate until darkening occurred. Diastatic power was expressed in L° units, which quantify enzymatic activity related to starch hydrolysis [18].

Antioxidant Compounds

Total polyphenol content was determined using the Folin–Ciocalteu method. The extraction was made with 80% methanol. Absorbance was recorded at 765 nm with an Evolution 201 spectrophotometer

(Thermo Fisher Scientific, Massachusetts, USA), and results were expressed as mg of gallic acid/100 g [19]. Total anthocyanin content was determined after extraction with an ethanol–HCl solution (4:1, v/v). The absorbance was measured at 400 nm, 515 nm, and 545 nm [20]. Total carotenoid content was determined after extraction with acetone and incubating it in the dark for two days [21]. The Absorbance was measured at 662 nm, 545 nm, and 470 nm. Antioxidant capacity was determined using the 2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) radical cation (ABTS). A aliquot of the methanolic extract was reacted with ABTS reagent. The absorbance was measured at 734 nm and the results are expressed in µg Trolox Eq/g of the sample [22]

2.3.3 Sensory acceptability analysis

The acceptance and sensory profile of a fermented beverage "*chicha*", sensory evaluation was performed under white light in a sensory evaluation laboratory. A total of 40 panelists participated (35 Ecuadorian people and 5 Korean people), who work at Santa Catalina Experimental Station, INIAP and Korea Partnership for Innovation of Agriculture (KOPIA). The evaluation included the fermented beverages produced from the five INIAP maize varieties, and a commercially available fermented beverage produced in Ecuador.

For acceptance testing, beverage samples were served in transparent cups labeled with randomly generated three-digit codes. Panelists evaluated color, aroma, taste, and consistency using a 7-point hedonic scale (1 = "dislike extremely" to 7 = "like extremely"). Additional comments from panelists regarding the samples were also recorded. Water rinsing was used between samples to reduce carry-over effects [23].

2.4 Statistical Analysis

All experiments were conducted in triplicate, and the results are expressed as mean ± standard deviation (SD). Statistical analysis was performed using GraphPad Prism 10 software (version 10.4; La Jolla, CA, USA).

3. Results

3.1 Physical analysis in raw samples

Table 1 summarizes the physical characteristics of the maize varieties. INIAP 101 had the highest kernel width (15.02 mm) and 1000-grain weight (600.67 g), while INIAP 199 exhibited the longest kernels (11.00 mm). INIAP 193 recorded the smallest kernel size (7.16 mm) and lowest 1000-grain weight (320.69 g). Additionally, INIAP 180 showed the highest kernel weight per volume (76.57 ± 0.46 g/mL), indicating a denser grain structure. Moisture content was lowest in INIAP 101 (8.02%) and INIAP 199 (10.29%), whereas INIAP 122 had the highest moisture (13.78%), with INIAP 180 and INIAP 193 at 11.29% and 10.62%, respectively.

Table 1
Physical characteristics of the maize varieties

Maize variety	Maize Size Width (mm)	Maize Size Length (mm)	TW (kg/hl)	TKW (g)	Moisture content %
INIAP 101	15.02 ± 1.21 ^a	10.06 ± 0.88 ^a	62.49 ± 0.8 ^b	600.67 ± 1.28 ^a	8.02 ± 0.42 ^a
INIAP 122	14.17 ± 1.73 ^a	9.65 ± 0.95 ^{ab}	60.91 ± 0.44 ^c	470.12 ± 0.82 ^c	13.78 ± 0.05 ^d
INIAP 199	14.90 ± 1.81 ^a	11 ± 1.68 ^a	61.73 ± 0.54 ^{bc}	410.32 ± 0.81 ^d	10.29 ± 0.13 ^b
INIAP 180	11.84 ± 0.88 ^a	9.59 ± 0.9 ^{ab}	76.57 ± 0.46 ^a	480.27 ± 0.87 ^b	11.29 ± 0.05 ^c
INIAP 193	11.5 ± 1.53 ^a	7.16 ± 0.62 ^b	63.08 ± 0.52 ^b	320.69 ± 0.35 ^e	10.62 ± 0.26 ^b

The length and width are presented as the mean ± standard deviation (SD) (n = 20), while the moisture content and the weight are expressed as the mean ± SD (n = 3).

Since the functional components of maize are closely associated with its color, a comparative analysis of color attributes was conducted for each variety. INIAP 122 had the highest luminosity ($L^* = 54.29$), indicating a relatively brighter appearance, while INIAP 199 showed the lowest luminosity ($L^* = 23.88$), suggesting a darker grain color. In terms of chromaticity (C^*), INIAP 122 exhibited the most vivid coloration ($C^* = 32.23$), primarily influenced by its high b^* value (31.68), which indicates a strong yellow component. In contrast, INIAP 199 had the lowest chroma ($C^* = 0.99$) and a negative b^* value (-0.74), suggesting a less saturated and possibly bluish hue. The hue angle (h^*) also varied significantly among the varieties. INIAP 101, 122, 180, and 193 had positive h^* values, ranging from 72.38° to 79.89°, indicating a brownish-yellow tone. INIAP 199 displayed a negative h^* value (-55.47), pointing to a markedly different hue that may shift towards a reddish or purplish tone.

Table 2
Color of the rind expressed in the CIELab* system of diverse maize grains studied

Maize variety	L* (Luminosity)	a* (red units)	b* (yellow units)	C* (chroma)	h* (hue)
INIAP 101	50.79 ± 2.98 ^a	2.61 ± 0.61 ^{bc}	14.75 ± 2.21 ^b	14.98 ± 3.25 ^b	79.89 ± 1.21 ^a
INIAP 122	54.29 ± 3.90 ^a	5.84 ± 1.40 ^{ab}	31.68 ± 3.65 ^a	32.23 ± 2.69 ^a	79.39 ± 1.91 ^a
INIAP 199	23.88 ± 2.33 ^b	0.51 ± 0.44 ^c	-0.74 ± 0.58 ^c	0.99 ± 0.59 ^c	-55.47 ± 3.10 ^b
INIAP 180	47.02 ± 2.80 ^a	6.52 ± 2.21 ^a	20.11 ± 3.01 ^b	21.16 ± 3.42 ^b	72.38 ± 3.20 ^a
INIAP 193	50.25 ± 2.21 ^a	4.63 ± 0.86 ^{ab}	20.80 ± 2.82 ^b	21.32 ± 2.82 ^b	77.32 ± 2.27 ^a

The data presented in the manuscript are expressed as the mean ± standard deviation (SD) (n = 20).

3.2 Chemical analysis

3.2.1 Total starch content, sugar content, and diastatic power in raw and germinated samples

In this study, we evaluated the changes in starch, sugar, and diastatic power content between raw and germinated samples. Regarding total starch content, all varieties except INIAP 101 and 193 increased upon germination. Similarly, total sugar content increased in all groups except for INIAP 180. In addition, diastatic power increased upon germination in all varieties (Fig. 1).

3.2.2 Functional compounds and antioxidant capacity in raw and germinated samples

This study analyzed functional components in five highland edible maize varieties. As shown in (a), total polyphenol (expressed as gallic acid) content increased upon germination across all varieties. Similarly, (b) demonstrates that antioxidant capacity also increases with germination. In contrast, (c) indicates that total anthocyanin content slightly decreased during germination. Regarding total carotenoid content (d), INIAP 199 and 193 exhibited decreased levels upon germination, whereas INIAP 101 and 122 showed slight increases and INIAP 180 displayed a marked increase.

3.2.3 pH, acidity and soluble solids during maize fermentation

Monitoring pH, acidity, and soluble solids content variations during fermentation. In this study, a traditional South American fermented beverage known as “Chicha” was produced by fermenting germinated corn flour over three days, during which daily measurements of pH, acidity, and soluble solids content were taken. All experimental groups exhibited a rapid decrease in pH throughout the three days of fermentation. Regarding acidity, all groups showed an increase on the first day, but on the second day, only INIAP 199 demonstrated a slight decrease. On the third day, acidity rose again in some groups while decreasing in others. Additionally, soluble solids content increased markedly on the first day and then either remained stable or slightly changed by the third day. These results suggest that pH, acidity, and sugar content undergo dynamic changes during the short-term fermentation of germinated maize.

3.2.4 Chemical characterization of fermented beverages

The fermented beverage called “Chicha”, a renowned South American fermented beverage uses germinated maize flour from five INIAP varieties and analyzes their functional components. No significant differences were observed in total starch content among the varieties. However, INIAP 193 exhibited a notably lower starch content (3.88 ± 0.46 g/100 g). Regarding total sugar content, INIAP 122 showed the highest concentration, while INIAP 180 and INIAP 193 had the lowest. Total polyphenol content was markedly elevated in INIAP 199, displaying a substantial increase relative to both raw and germinated samples. Similarly, the other maize varieties also exhibited higher polyphenol levels in the fermented beverage compared to their raw and germinated states. In contrast, antioxidant capacity decreased significantly in all fermented samples compared to raw and germinated samples, although INIAP 199 still showed the highest activity among them. Total anthocyanin content was detected only in INIAP 199, and its level tended to decrease relative to the raw and germinated samples. Finally, while carotenoids were undetectable in INIAP 101, a considerable amount was present in the INIAP 180 sample. However, the carotenoid content in INIAP 180 was lower in the fermented beverage than in the germinated sample.

Table 3
Chemical characterization of fermented beverages made with five diverse maize varieties

Maize variety	Total starch content (g/100g)	Total sugar content (Brix°)	Total polyphenol content (mg GA/g)	Total anthocyanin content (mg/g)	Total carotenoid content (mg/g)	Capacity of Antioxidant (uM Eq Trolox/g)
INIAP 101	5.53 ± 1.22 ^{ab}	6.00 ± 0.29 ^{ab}	3.10 ± 0.99 ^b	ND	ND	0.26 ± 0.046 ^b
INIAP 122	6.94 ± 1.00 ^a	7.00 ± 0.29 ^a	3.15 ± 0.791 ^b	ND	0.23 ± 0.09 ^b	0.29 ± 0.02 ^b
INIAP 199	6.40 ± 1.52 ^{ab}	6.00 ± 0.29 ^{bc}	10.43 ± 2.36 ^a	64.79 ± 0.68	0.12 ± 0.15 ^b	0.64 ± 0.063 ^a
INIAP 180	6.12 ± 1.10 ^{ab}	5.00 ± 0.58 ^{bc}	1.81 ± 0.25 ^b	ND	1.29 ± 0.08 ^a	0.20 ± 0.03 ^b
INIAP 193	3.88 ± 0.46 ^b	5.00 ± 0.29 ^c	4.69 ± 2.15 ^b	ND	0.29 ± 0.14 ^b	0.28 ± 0.03 ^b

The data presented were expressed as the mean ± standard deviation (SD) (n = 3), Nd: no detectable.

3.3 Sensory evaluation of the fermented beverages

The results showed that color preference was highest for INIAP 199, a black corn variety, while INIAP 180, a white corn variety, received the lowest score. In terms of smell, all samples received similar scores except for INIAP 180, which had a notably lower rating. Regarding flavor, INIAP 193 was rated the highest, whereas INIAP 180 received the lowest score. For consistency, INIAP 122 had the highest score, while INIAP 180 scored the lowest. Overall quality, INIAP 199 achieved the highest total score, the commercial beverage ranked fourth, and INIAP 180 received the lowest score (Table 4 and Fig. 5).

Table 4
Sensory Evaluation Scores of Fermented Beverages

Maize variety	Color	Smell	Flavor	Consistency	Overall quality
INIAP 101	4.50 ± 1.10 ^d	5.08 ± 1.13 ^a	4.90 ± 1.24 ^a	5.00 ± 1.32 ^a	4.92 ± 1.29 ^{ab}
INIAP 122	5.23 ± 0.96 ^{bc}	5.23 ± 1.17 ^a	5.20 ± 1.14 ^a	5.38 ± 1.02 ^a	5.28 ± 1.08 ^a
INIAP 199	6.20 ± 0.8 ^a	5.18 ± 1.05 ^a	5.05 ± 1.26 ^a	5.15 ± 1.31 ^a	5.40 ± 1.31 ^a
INIAP 180	4.12 ± 1.2 ^d	3.25 ± 1.53 ^b	3.53 ± 1.53 ^b	3.80 ± 1.20 ^b	4.09 ± 1.73 ^b
INIAP 193	5.00 ± 1.04 ^c	5.48 ± 1.00 ^a	5.55 ± 0.97 ^a	5.05 ± 1.05 ^a	5.29 ± 1.04 ^a
Commercial Product	5.60 ± 1.05 ^b	5.15 ± 1.31 ^a	4.80 ± 1.86 ^a	4.70 ± 1.93 ^{ab}	5.04 ± 1.64 ^a

The data were expressed as the mean ± standard deviation (SD) (n = 40), and the total score is out of 7 points.

4. Discussion

The physical characteristics of maize indicate the variability among varieties. This variability is influenced by the geometric shape and weight of the grain. TW and TKW are used to determine the yield of cereal before harvest [24, 25]. INIAP 101 and INIAP 180 varieties exhibited higher weight and moderate moisture content relative to the other material. The maize varieties exhibited different colors, including orange, yellow, white and purple. This variation in color may have influenced the beverage and affected the sensory perception of the panelist. The color variation is associated with the presence of secondary metabolites, including phenolic compounds, anthocyanins, and carotenoids [26]. The CIELAB system allows the presence of pigments, which can provide indirect information about the presence of pigments in maize varieties. The yellow maize varieties (INIAP 122, 180, and 193) exhibited high carotenoid content. The yellow corn is considered the main source of Lutein, zeaxanthin and α-cryptoxanthin [27]. The deep pigmentation of INIAP 199 was associated with higher anthocyanin and polyphenol content. The physical results revealed significant varietal differences in both morphological characteristics and functional component profiles.

This study assessed changes in soluble solids, starch content, diastatic power, and functional compounds, including antioxidant activity, as well as overall chemical composition across three processing stages (raw, germinated, and fermented) in five improved maize varieties cultivated in the

high-altitude regions of Ecuador. The germination process modifies the starch structure and physicochemical properties of starch [28]. Notably, an analysis of the effect of germination on total starch and sugar content showed an increase in total starch in most varieties post-germination, except for INIAP 101 and 193, which exhibited a decrease. Typically, starch degradation during germination is associated with the increased activity of hydrolytic enzymes such as α -amylase and β -amylase [28, 29]. Other studies on grain germination, a reduction in this component has been reported; however, the increase in starch observed in that study may be the lower amylase activity in certain varieties due to differences in starch metabolism enzyme activity and the partial resynthesis of starch through the action of specific enzymes (e.g., ADP-glucose pyrophosphorylase, starch synthase) [30]. Additionally, total sugar content increased in all varieties except for INIAP 180, which can be attributed to the hydrolysis of starch into simpler sugars.

Diastatic power is defined by the total concentration of starch degrading enzymes present in the grain [31]. In this study, the increase in diastatic power in all varieties post-germination suggests the conversion of the bound form of β -amylase to the active free state through proteolytic cleavage which occurred during germination [31, 32]. This increase in enzyme activity could play a significant role in processing and fermentation.

Functional component analysis revealed an increase in total polyphenol content and a corresponding rise in antioxidant activity across all varieties during germination. This enhancement may be due to the activation of phenylpropanoid metabolism during germination, particularly through the upregulation of enzymes such as phenylalanine ammonia-lyase (PAL), which play a key role in phenylpropanoid- and tyrosine-derived branch [33]. Additionally, the breakdown of cell wall components may improve the extractability of existing phenolic compounds, as supported by previous studies [34].

Anthocyanin content was recorded only in the INIAP 199 variety, and a slight decrease in this compound was observed after germination, likely due to its structural instability and susceptibility to enzymatic degradation. Therefore, the observed reductions in this compound is more likely attributed to factors such as oxidation, pH fluctuations, or enzyme activity [34]. By other hand, the anthocyanin content of the white and yellow maize cultivars was undetectable.

Carotenoid content also varied by maize varieties, with INIAP 180 showing a marked increase and INIAP 199 and 193 exhibiting reductions, suggesting varietal differences in metabolic regulation and endogenous enzyme expression. During germination process, the increase in INIAP 180, may be due to the photomorphogenesis process, in which light influences carotenoid biosynthesis [35]. However, in other varieties the decrease of carotenoids content was observed during germination, which may be attributed to external factors such as light, oxygen, and temperature [36].

During the fermentation beverages, a marked decrease in pH was observed in all varieties early in fermentation, indicating a natural result of organic acid production. Acidity increased in all varieties on the first day, but INIAP 199 showed a slight decrease on the second day, with subsequent variations on the third day, likely due to differences in microbial community changes and organic acid production rates

[37]. Soluble solids content sharply increased at the start of fermentation and then gradually decreased, suggesting that simple sugars formed during germination were metabolized by microbes [38]

Functional component analysis of fermentation beverage showed no significant differences in total starch content among varieties, although INIAP 193 had the lowest content. The highest total sugar content was observed in INIAP 122, while INIAP 180 and 193 showed the lowest. The highest total polyphenol content was maintained in INIAP 199 post-fermentation, indicating its high potential as a functional food. However, antioxidant activity decreased in all fermented samples. The quantity of antioxidant compounds analyzed is dependent on the water content in the fermented beverage.

Sensory evaluation revealed that the black-colored variety (INIAP 199) had the highest color preference, while the white variety (INIAP 101) received the lowest scores. This may reflect consumer associations between darker pigmentation and perceived health benefits. Notably, INIAP 199 also exhibited the highest levels of antioxidant compounds, including polyphenols and anthocyanins, which are well-documented for their roles in reducing oxidative stress and preventing chronic diseases [39, 40]. The superior functional profile of this purple maize variety may support its potential for use in health-oriented food products. In terms of aroma, most samples received similar scores, but INIAP 180 was rated lower, possibly due to the presence of undesirable volatile compounds produced during fermentation [41]. Overall, INIAP 199 received the highest preference score, while the commercially developed commercial beverage was rated fourth. The characteristics of raw materials, fermentation conditions may influence the physical and sensory characteristics of the beverage [27].

This study is significant for its scientific evaluation of the nutritional value and functionality of improved maize varieties grown in high-altitude regions. The findings contribute to the development of high-value functional foods using these corn varieties and offer new economic opportunities for small-scale farmers in Ecuador.

Conclusion

This study evaluated changes in the nutritional and functional properties of five improved maize varieties cultivated in the high-altitude regions of Ecuador across three processing stages: raw, germinated, and fermented. The results demonstrated significant varietal differences in starch and sugar metabolism, enzymatic activity, and bioactive compound profiles, particularly in response to germination and fermentation. While germination increased sugar content and antioxidant activity by enhancing enzymatic and polyphenol levels, fermentation induced notable shifts in acidity and functional compound stability. Notably, INIAP 199, the variety with the highest polyphenol and anthocyanin content, also received the highest overall sensory preference, highlighting a rare and promising convergence between nutritional quality and consumer acceptance. These findings provide valuable insights for the development of functional maize-based products.

Declarations

Consent to participate

The sensory protocol was approved by the Institutional Review Board (IRB) of the Santa Catalina Research Site (Committee Minute No. 047-2024).

Consent to publication

Not applicable

Competing interests

The authors declare no competing interests.

Plant ethics

Maize varieties were provided by Programa de Maíz, (INIAP), Mejía, Ecuador. These varieties were harvested from the Estación Experimental Santa Catalina (INIAP) and farmers' locations in the province of Cotopaxi, Ecuador. The collection and use of plant material complied with the relevant institutional and national regulations. No specific permits or licenses were required.

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Author Contribution

Conceptualization: H.J.K., E.V, J.L.Z., C.SU. and C.SA.; Methodology: H.J.K, M.Q . and E.V.; Software: H.J.K. and M.Q.; Validation: J.L.Z., C. SU. and A.P; Formal analysis: H.J.K. and M.Q.; Investigation: H.J.K, M.Q., E.V., J.L.Z., C.SU., C.SA. and A.P; Data curation: H.J.K., M.Q., and E.V.; Writing-original draft: H.J.K. and M.Q.; Writing-review and editing: M.Q, E.V.; J.L .Z.; C.SU., Ca SA. and A.P; Supervision: E.V., C.SU, and J.L.Z.;Resources, Project administration and Funding acquisition: Kopia Ecuador Center. All authors have read and agreed to the published version of the manuscript.

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Data Availability

All data related to the research are included in the manuscript; any other data will be available upon request.

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Figures

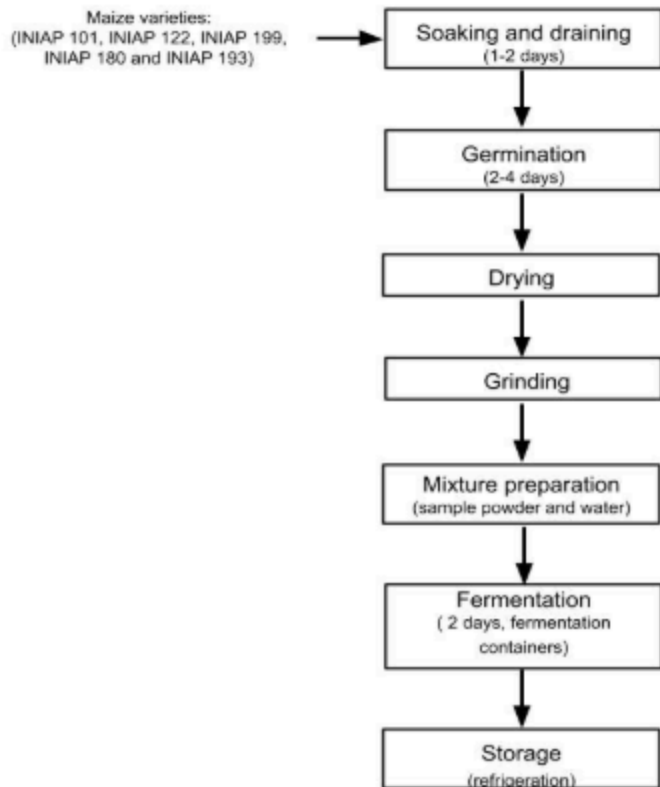


Figure 1

Flow diagram for sample preparation

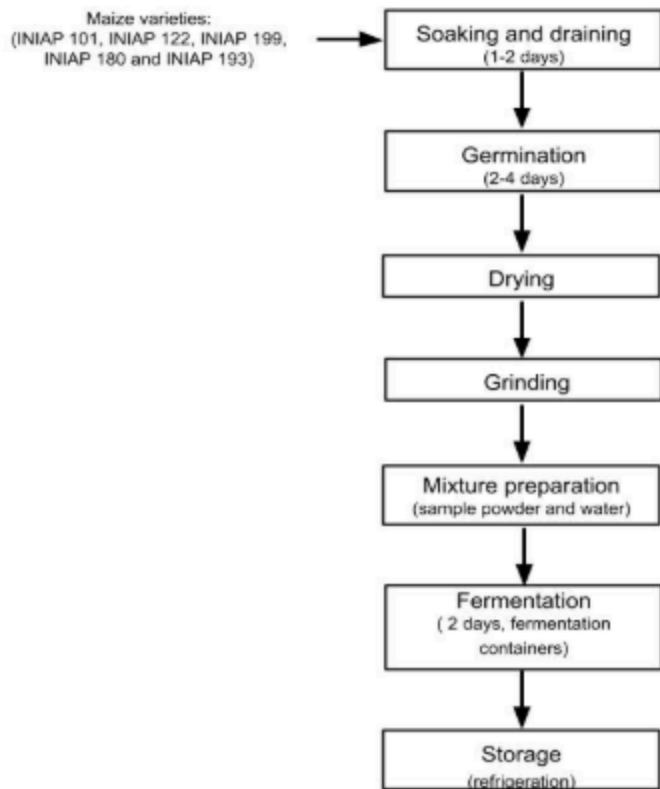


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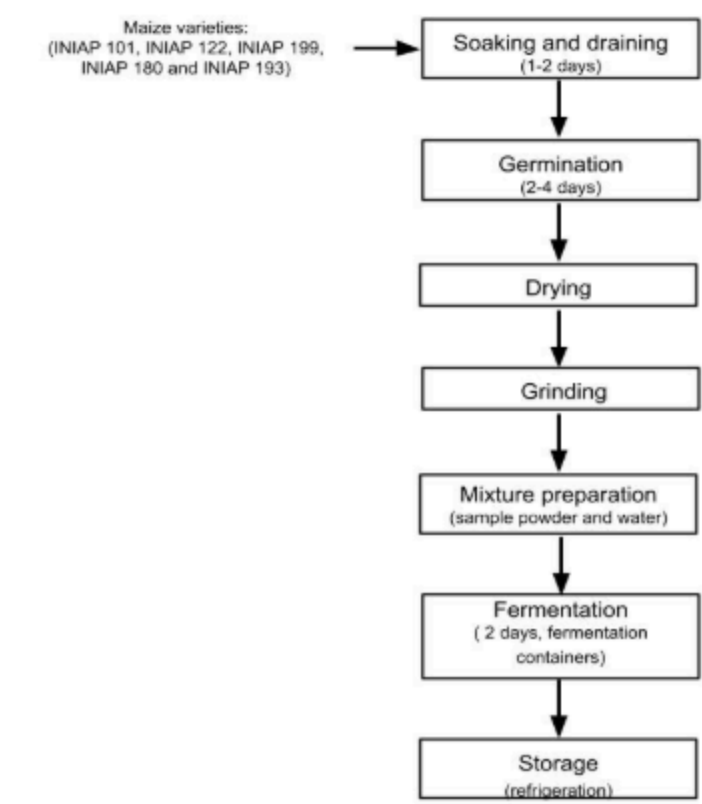


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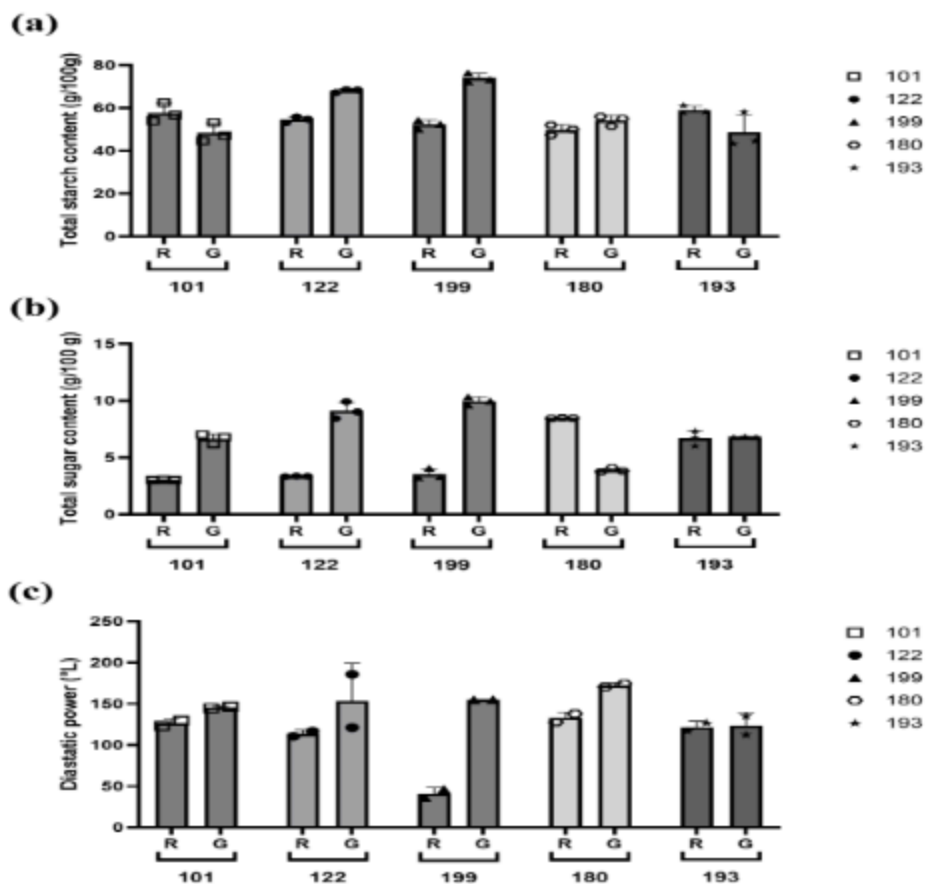


Figure 2

Total starch content, sugar content, and diastatic power in selected maize varieties. Five highland edible maize varieties were analyzed for total starch, sugar, and diastatic power. (a) displays the total starch content, (b) shows the total sugar content, and (c) illustrates the diastatic power. All experiments were conducted in triplicate, and the data represent the mean $\pm$ standard deviation (Data expressed on a dry basis)

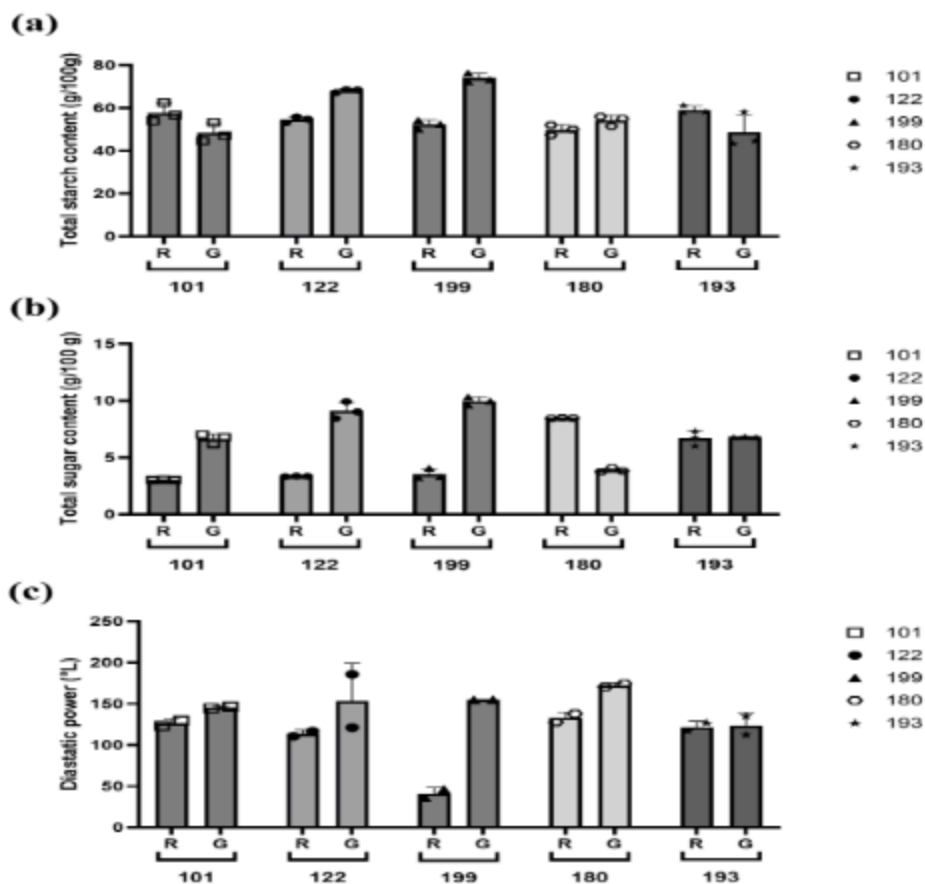


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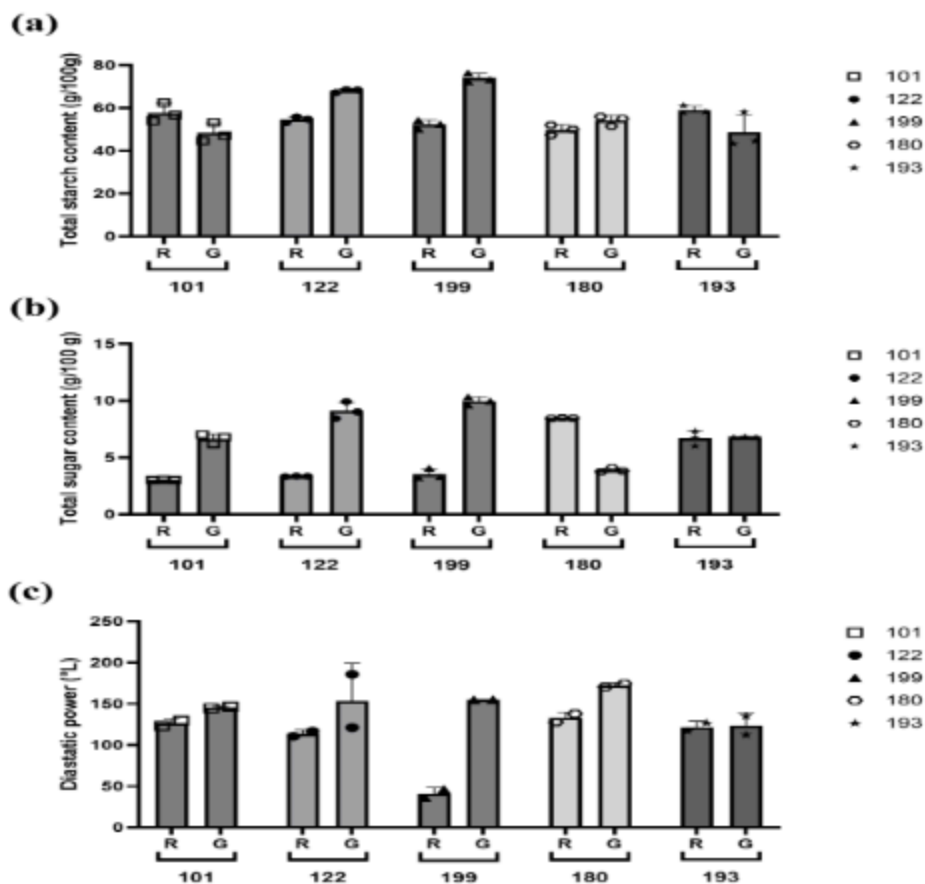


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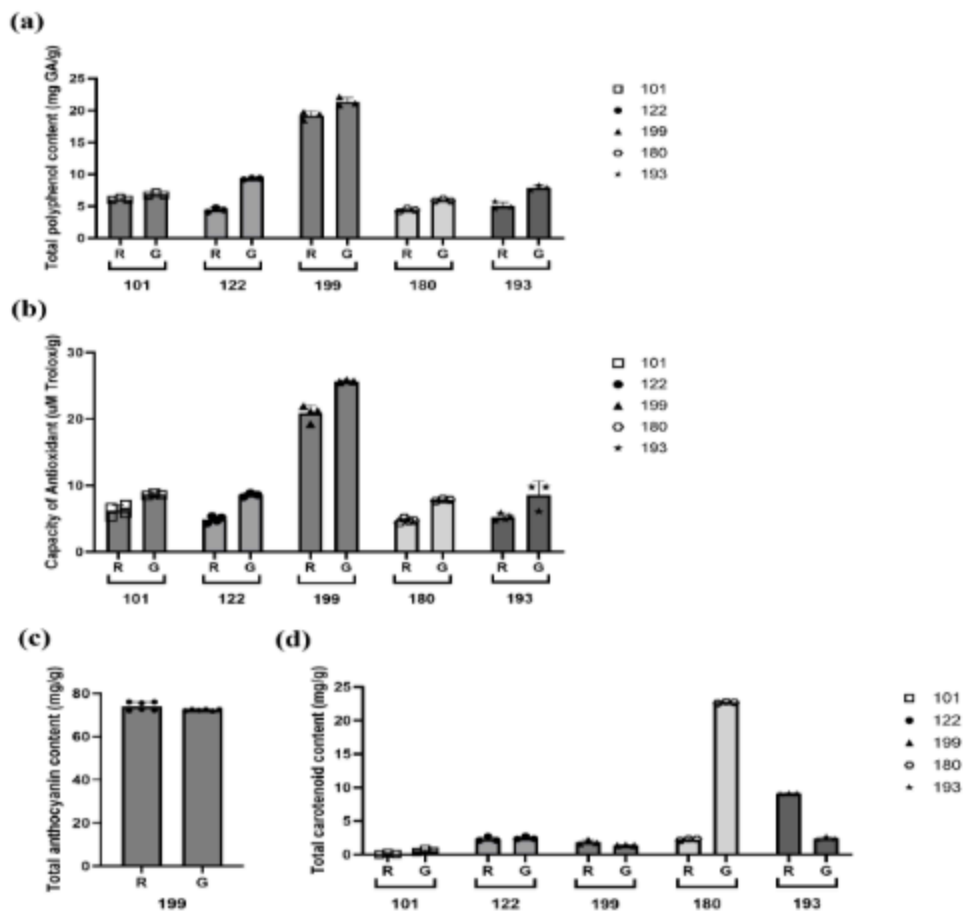


Figure 3

Comparative Analysis Compounds and Antioxidant Properties in Maize Varieties. Functional components of five INIAP corn varieties. (a) illustrates the total polyphenol content, (b) displays the antioxidant capacity, (c) presents the total anthocyanin content, and (d) depicts the total carotenoid content. All experiments were conducted in triplicate, and the data represent the mean $\pm$ standard deviation (Data expressed on a dry basis)

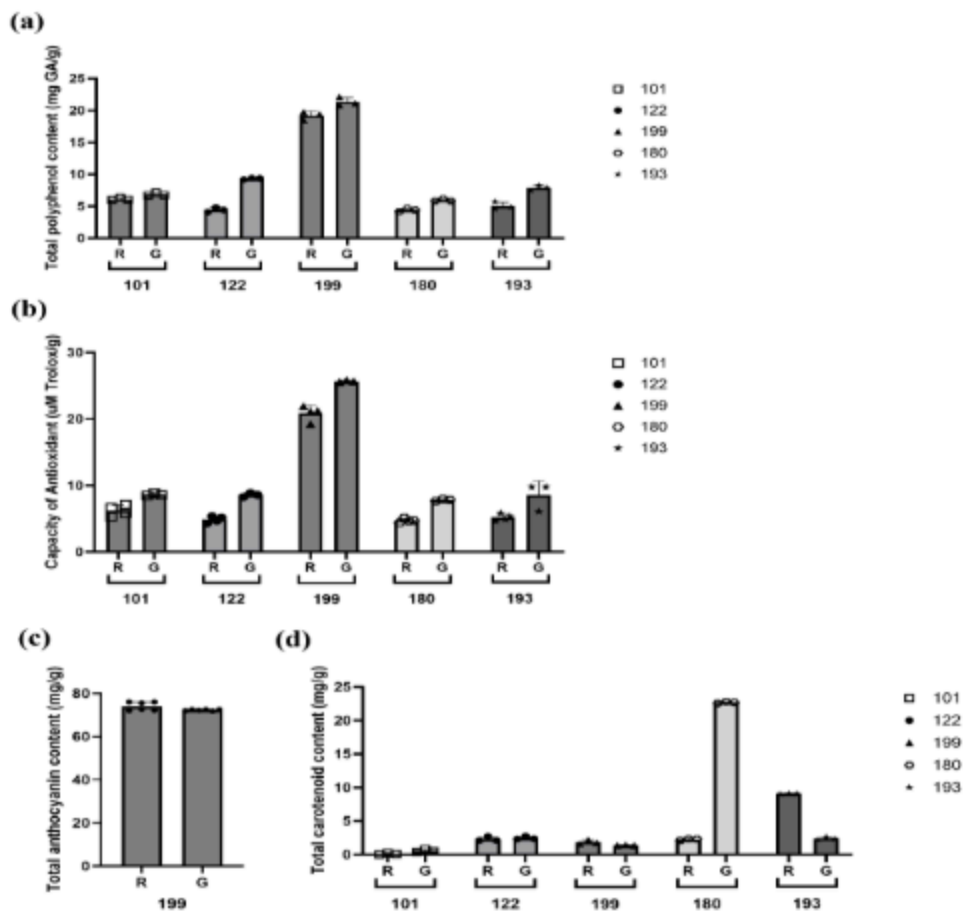


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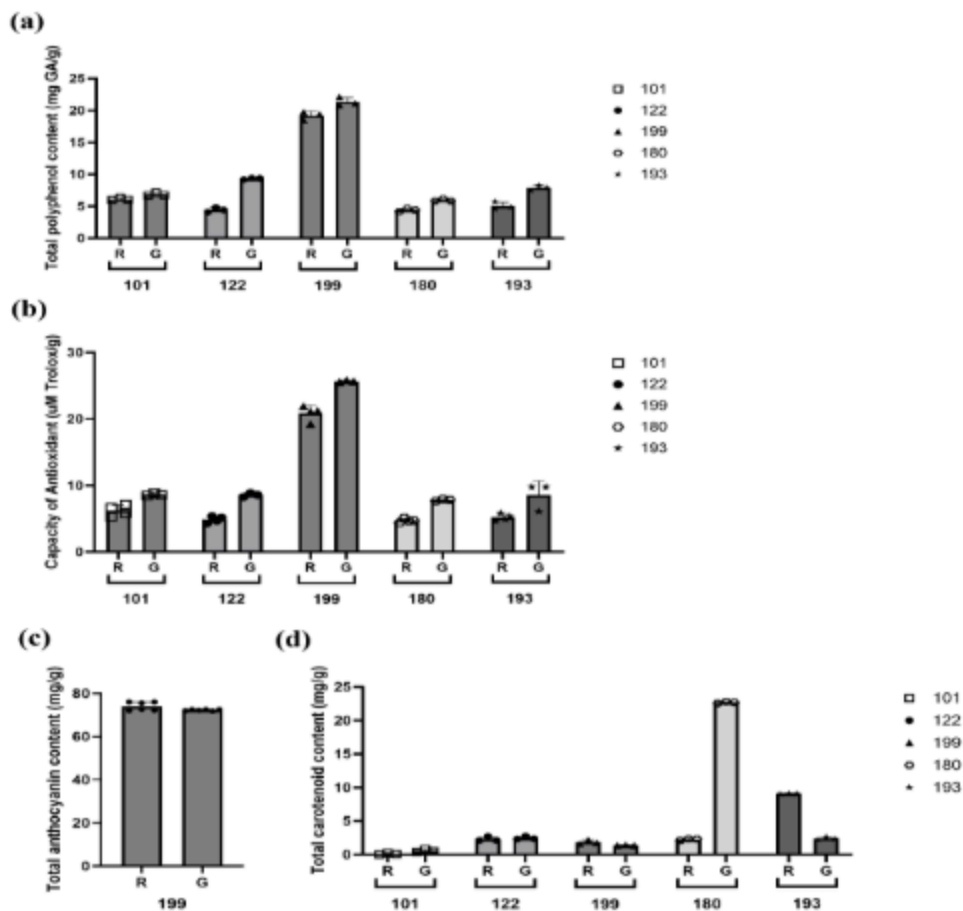


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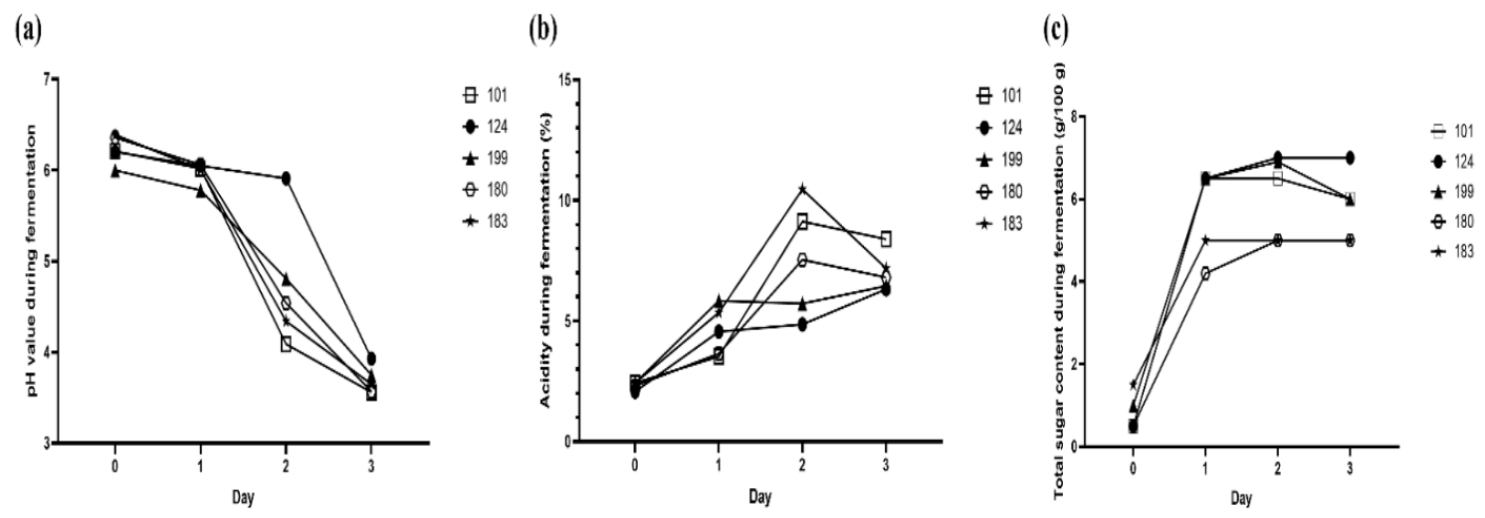


Figure 4

Temporal Dynamics of pH, Acidity, and soluble solids Content During Fermentation. pH (a), acidity (b), and soluble solids content (c). All experiments were conducted in triplicate, and the data represent the mean $\pm$ standard deviation

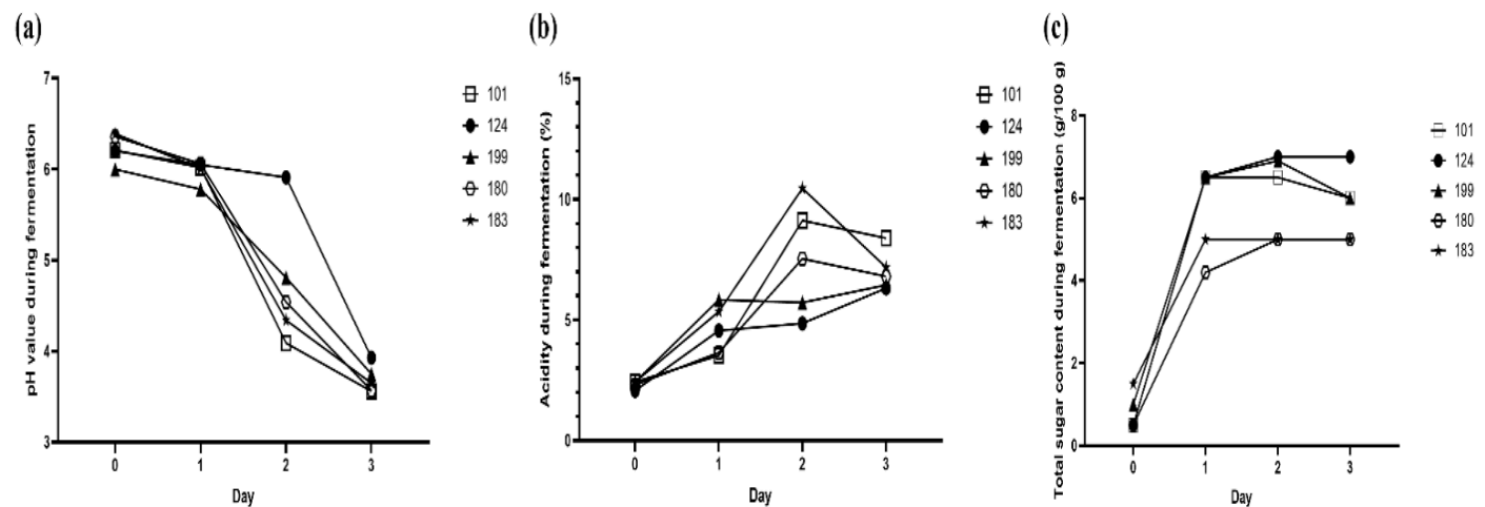


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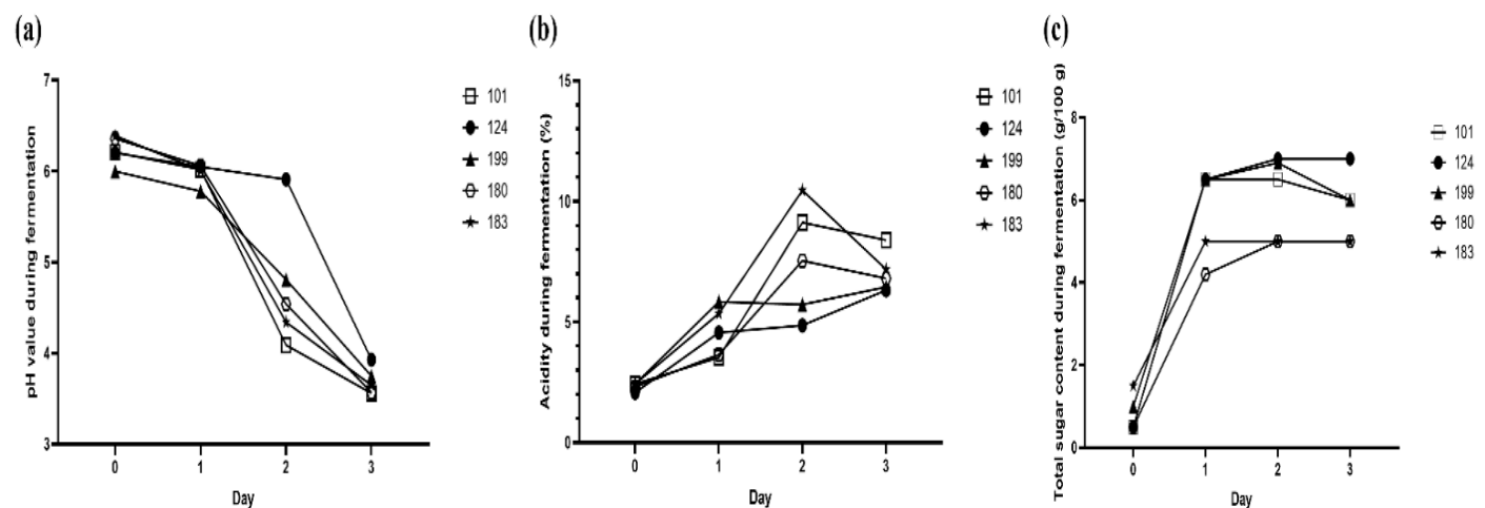


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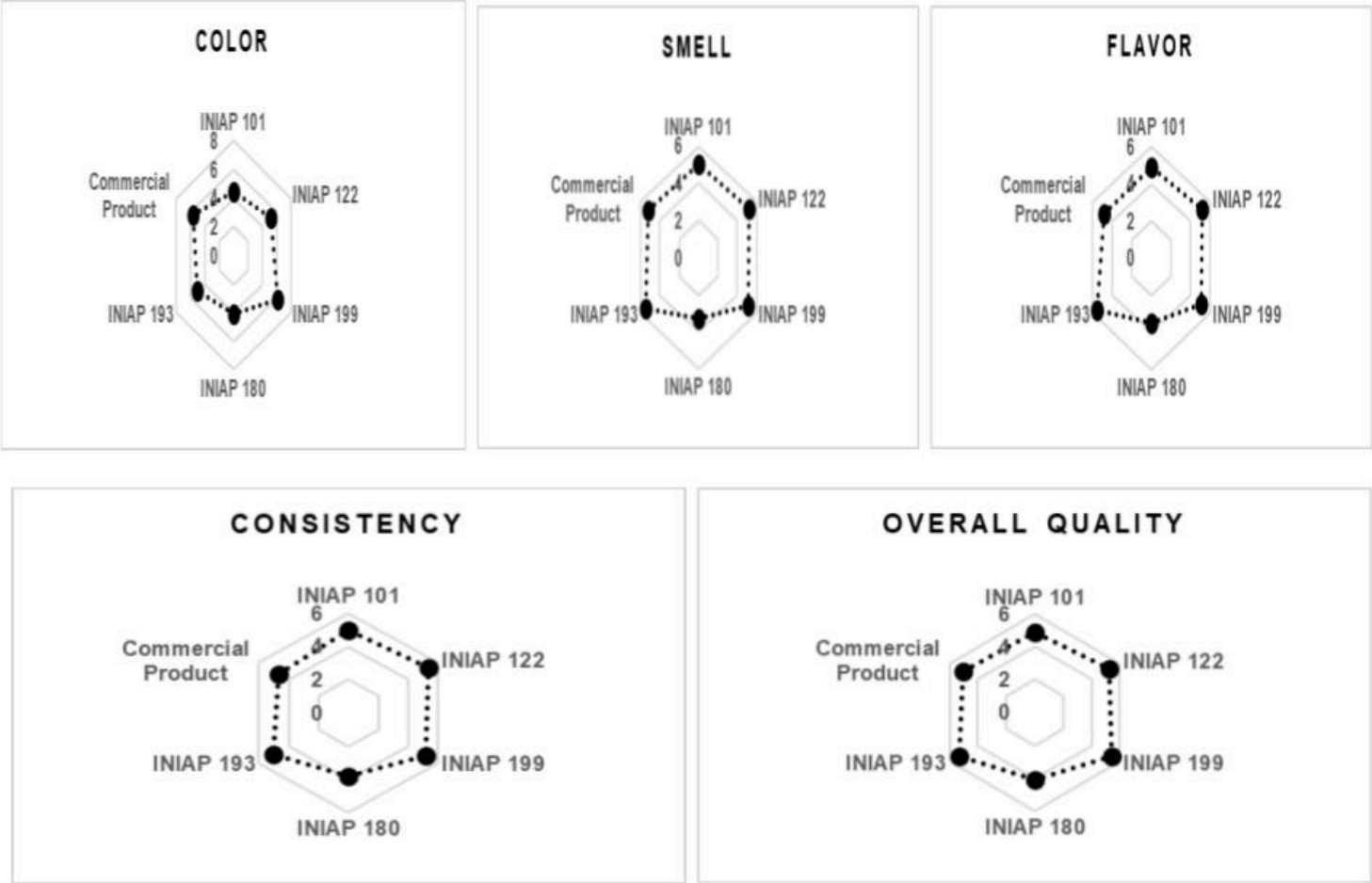


Figure 5

Comparison of Sensory Evaluation Scores across different maize varieties

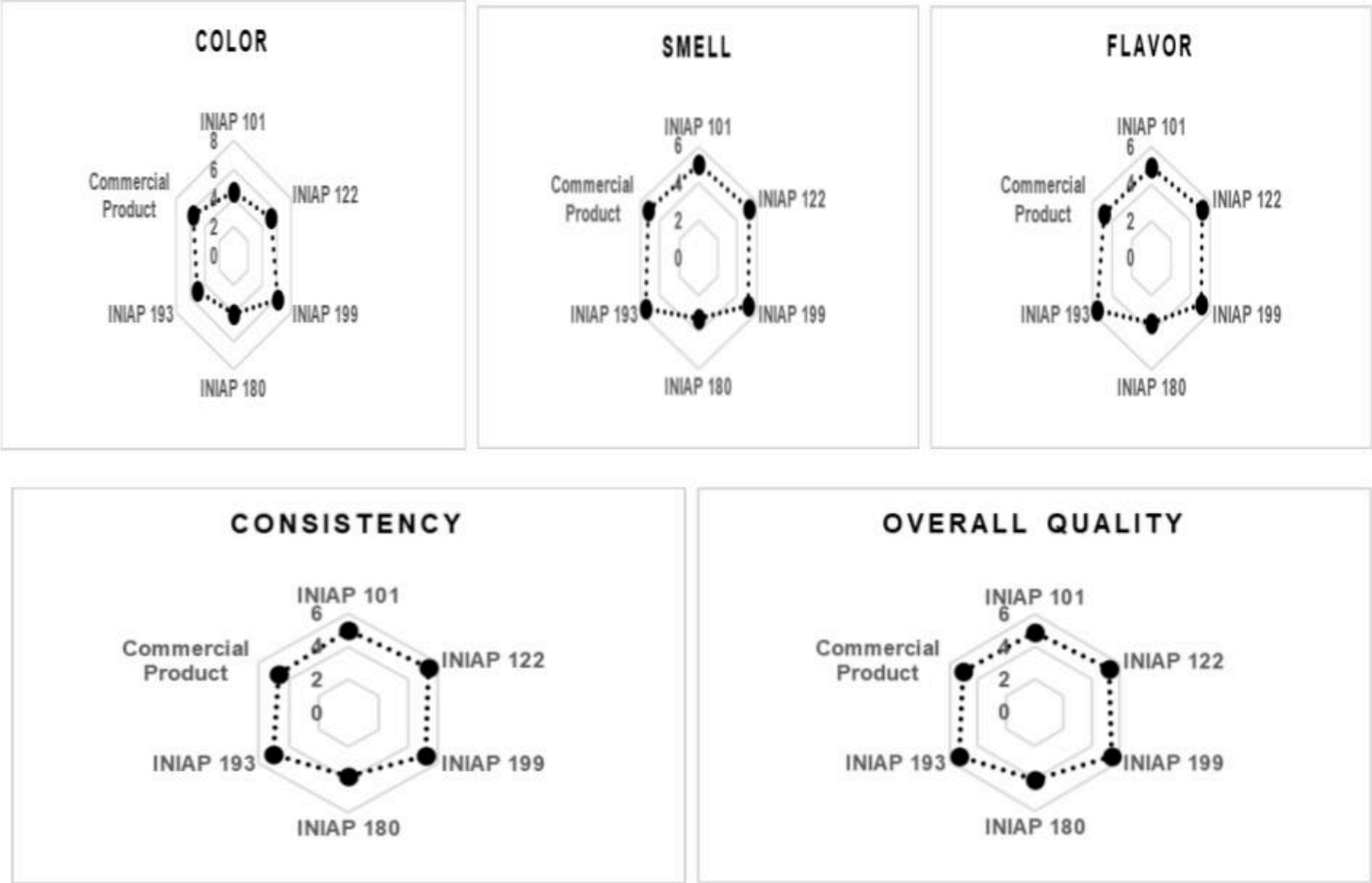


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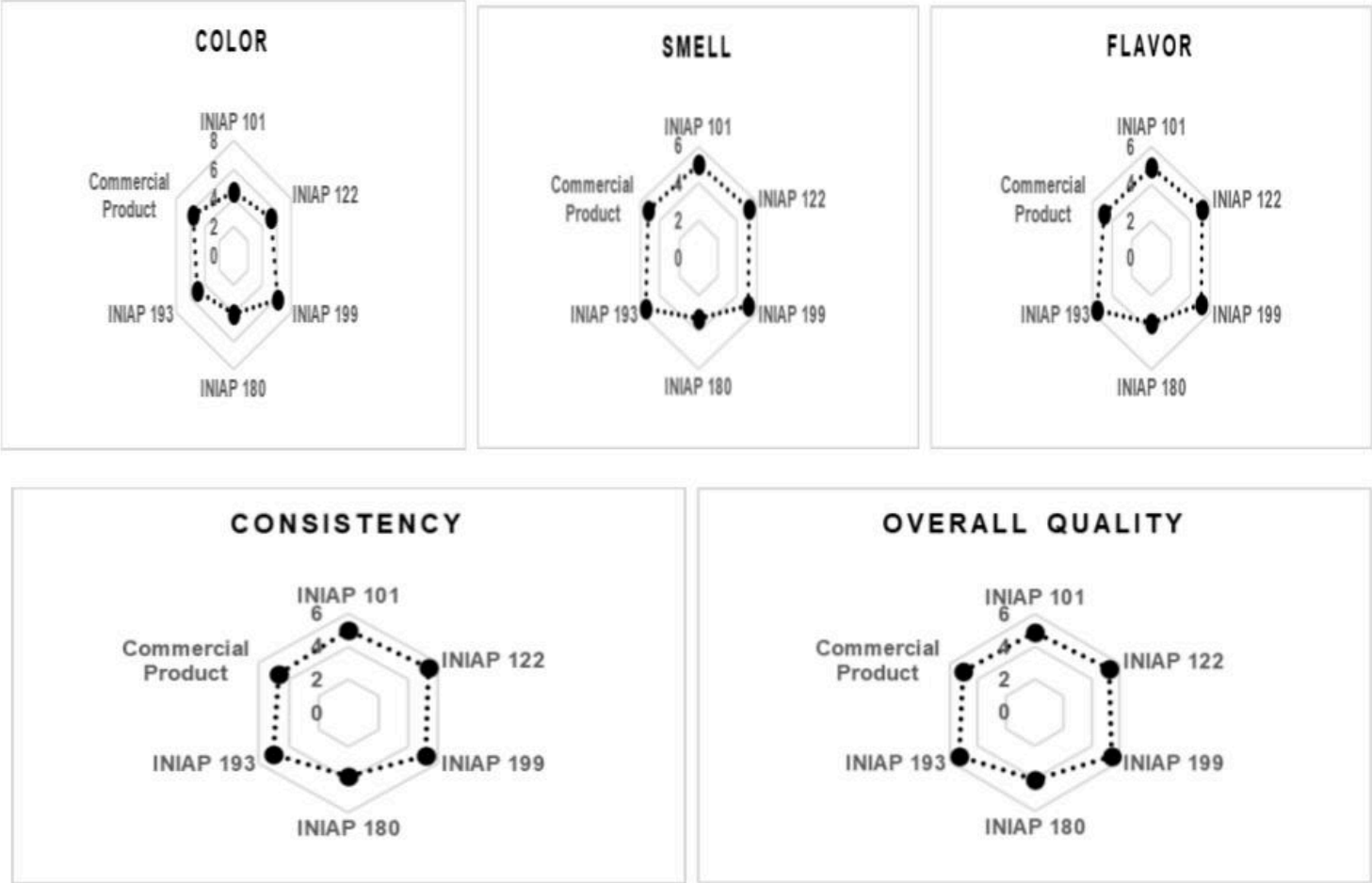


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