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Sensory Acceptability of Soynuts Compared to Popular Nut Snacks: Prospects for Addressing Malnourishment among the South African Youth

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Abstract
Healthier snack alternatives must be accessible to all segments of society, including low-income households that often rely on ready-made options from informal shops and street vendors. It is not enough for these snacks to be convenient; they must also deliver meaningful nutrition. For example, plant-based protein-rich options such as roasted soynuts can provide both affordability and health benefits, ensuring that families do not have to choose between cost and nutrition. By bridging the gap between convenience, affordability, and nutritional value, the production of such snacks can support public health while contributing to sustainable food systems. The aim of this study was to compare a laboratory-developed snack nut called "soynuts" prepared from soybean (*Glycine max*) grains with chickpeas (*Cicer arietinum),* peanuts (*Arachis hypogaea*), and almonds (*Prunus dulcis*) in terms of consumer acceptability and nutritional content. The samples were analysed for sensory analysis, crude protein, fat, and ash content. Peanuts and almonds were highly liked, chickpeas were disliked slightly, while soynuts were neither liked nor disliked. Soynuts were very high in crude protein (39.068 g) and neutral detergent fibre (30.267 g). The calcium content was similar between the soynuts (0.030 mg/100 g) and the almonds (0.030 mg/100 g). The potential for further development of the soynut snack and its value chain is promising; however, innovations are needed to enhance sensory attributes such as shape and colour to make it more appealing to consumers.

Keywords: nutritious, youth, affordability, nuts, consumer acceptability, soybean.

1. Introduction

Despite post-apartheid progress, South Africa is still facing malnutrition and health challenges, mainly as a result of poverty and economic hardship (Azomahou et al., 2022; Prioreschi et al., 2017). This intersection of economic instability and changing dietary habits has compromised food security, creating a complex triple burden of malnutrition characterised by the co-existence of undernutrition, overnutrition, and micronutrient deficiencies (Alaba et al., 2023; Zemene et al., 2023). Undernutrition remains a critical health challenge in South Africa (Iversen et al. 2012). Despite

persistent growth faltering, there is a rising trend of early childhood adiposity (Kaldenbach et al., 2022; Nyati et al., 2019).

South Africa is undergoing a "nutrition transition" that has shifted diets from traditional staples towards cheap, energy-dense, ultra-processed foods high in sugar, salt, and fat (Azomahou et al., 2022; Prioreschi et al., 2017; Reardon et al., 2021), particularly in low-resource households (Messina, 2022; Saaka et al., 2017). This shift drives an epidemiological change, where rising obesity and non-communicable diseases (NCDs), such as Type 2 diabetes, hypertension, and cardiovascular diseases, co-exist with persistent undernutrition (Azamahou et al., 2022; Prioreschi et al., 2017). This triple burden of malnutrition exceeds rates in many other African nations (Akombi et al. 2019; Mbogori et al., 2020), escalating the morbidity and mortality risks, burdening health care systems, and diminishing economic productivity (Mbogori et al., 2020).

Addressing these diverse nutrition challenges has become critical. The South African snack market is dominated by maize chips (40%), potato chips (20%), and puffs (10−15%), while gums and jellies lead the sugar confectionery sector (Eagle, 2019). Most available options are high in added sugars and salt and inconsistent with healthy dietary recommendations to combat over- and undernutrition (Ibiyemi & Oldewage-Theron, 2023; Pries et al., 2019). Consequently, there is a clear demand for convenient, palatable alternatives that support a balanced diet.

There is also a growing consensus among the food and nutrition sector to promote and produce plant-based food items (Henchion et al., 2017; Ismail et al., 2020; Kiesselbach & Pissarskoi, 2023) that mimic the sensory attributes of similar food products, but with minimal negative environmental impact. Undernourished children often lack high-quality protein in their diets. Soybeans offer a locally available, affordable solution, providing essential proteins, fatty acids, micronutrients, and antioxidants that protect against nutrition-related NCDs. Their high dietary fibre promotes gut health and satiety, aiding weight management. Additionally, soy is a versatile, gluten-free, and lactose-free alternative for children with specific dietary restrictions or allergies. In addition, soy is locally available, acceptable, and affordable in South Africa.

Despite their health benefits, soy snacks have low consumption rates among South Africans due to perceived high costs (Herforth et al., 2020; Wrottesley et al., 2020). Consequently, research into affordable, innovative alternatives is essential. Soynuts—which emulate the taste and texture of popular savoury snacks—could provide a healthy, cost-effective option, yet studies on their nutritional value and consumer acceptability in South Africa remain limited. This study thus investigated the descriptive sensory characteristics and consumer acceptance of four popular legume nuts available on the South African market compared to soynuts to evaluate consumer needs and preferences.

2. Materials and Methods

2.1 Sampling

In this study, nuts derived from different legume plant sources were utilised. Commercially available varieties—almonds, peanuts, and chickpeas—were included, while soybeans were donated by the Enden Social Development Foundation (Drakensburg Terrace Accommodation, Berville, 3350).

2.2 Chemical and Nutritional Composition Analysis

The chemical analysis of each of the snacks was carried out in the Animal Science Laboratory of the University of the Free State, South Africa. The analysis was conducted on similar sample quantities of dried plain and unflavoured nuts that have been roasted using a domestic air-fryer machine (Kenwood – 5.5L kHealthy Fry XXL – HFP50.000WH) at the same temperature and time. The chemical composition of the soynut, peanut, almond, and chickpea snacks was analysed using the following methods.

2.2.1 *Crude fat (Soxhlet method)*

Crude fat was extracted from the sample using ether, which was then evaporated from the flask, leaving only the fat. This was determined using the method described by the Association of Official Analytical Chemists International (1995).

2.2.2 *Crude protein (Dumas combustion method)*

Crude protein was determined using the Dumas combustion method for nitrogen determination, based on the transformation of the sample to a gas phase by extremely rapid and complete flash combustion of the sample material. This method was described by Hauck (1982) and Kirsten (1983).

2.2.3 *Neutral detergent fibre (NDF)*

Neutral detergent fibre was determined by dissolving the cell contents of the sample with a neutral detergent solution, leaving only the cell wall fraction consisting of hemicellulose, cellulose, lignin, cutin, and silica. This method was described by Robertson and Van Soest (1981).

2.2.4 *Calcium and magnesium (Atomic absorption flame spectroscopy)*

Calcium and magnesium concentrations were determined using atomic absorption flame spectroscopy. The methods used were described by the Association of Official Analytical Chemists (1990), GBC Scientific Equipment PTY Ltd. (1991), and Price (1972).

2.2.5 *Potassium and sodium (Flame emission spectroscopy)*

Potassium and sodium concentrations were determined using flame emission spectroscopy. The methods used were described by Poluektov (1973), and the Technicon Instruments Corporation (1978).

2.3 Sensory Analysis

2.3.1 *Recruitment of participants*

Convenience sampling in the form of non-probability sampling was employed, where the participants had to meet certain criteria, such as being within a certain age limit, not being allergic to soybean and nut products, being easily accessible, being available (geographical proximity), and being willing to participate in the study (Andrade, 2021). A total of 103 consumers were recruited to participate in the sensory evaluation task. Consumers were recruited two weeks in advance using invitation emails, which were sent to former participants of sensory studies. The consumers were in the 18−23-year age bracket and consisted only of students. These participants were recruited from the UFS undergraduate and postgraduate student cohort, thereby representing the South African youth age group of 18 to 23 years.

2.3.2 *Sample preparation*

Soybean grains were stored at 0 °C in a cold room and used in the experiment. Roasting nuts is one of the most common and preferred cooking methods for snacking in South Africa. Therefore, the samples were roasted at 25 °C using an air-frying method. The nut samples were freshly prepared using Kenwood – 5.5L kHealthy Fry XXL – HFP50.000WH at 180°C for 12 minutes.

2.3.3 *Presentation of the samples*

The sensory evaluation was conducted following the methodology described by Montenegro et al. (2015), with minor modifications. One hundred and three (103) panellists from various demographics (18–23 years) with no training in sensory evaluation techniques participated in this study. First, the general concept of the study was introduced to the participants, followed by an in-depth explanation of the test and sensory descriptors used. For instance, for each sensory attribute, the methodology involved initial demonstrations using standard materials that exemplify the extreme sensory characteristics, along with corresponding definitions and descriptive terms. The participants were then asked to evaluate five roasted samples on similar attributes investigated for the study. The investigated attributes were colour, shape, nutty aroma, flavour, and texture. The participants were given approximately 25 g of each sample.

Participants were not allowed to eat or drink anything other than water one hour prior to the sensory evaluation procedure. They were instructed to rinse their mouths with spring water before and between each sample. Each sample was assigned a unique three-digit code (see Figure 1) on a white polystyrene tray under white lights in the sensory booths at the Sensory Lab, Department of Sustainable Food Systems and Development, University of the Free State. The sensory evaluation was conducted at room temperature (25 ± 2°C) and at controlled relative humidity (75%). A 9-point scale (ranging from "1 = *not at all*" to "9 = *extremely strong*") was used.

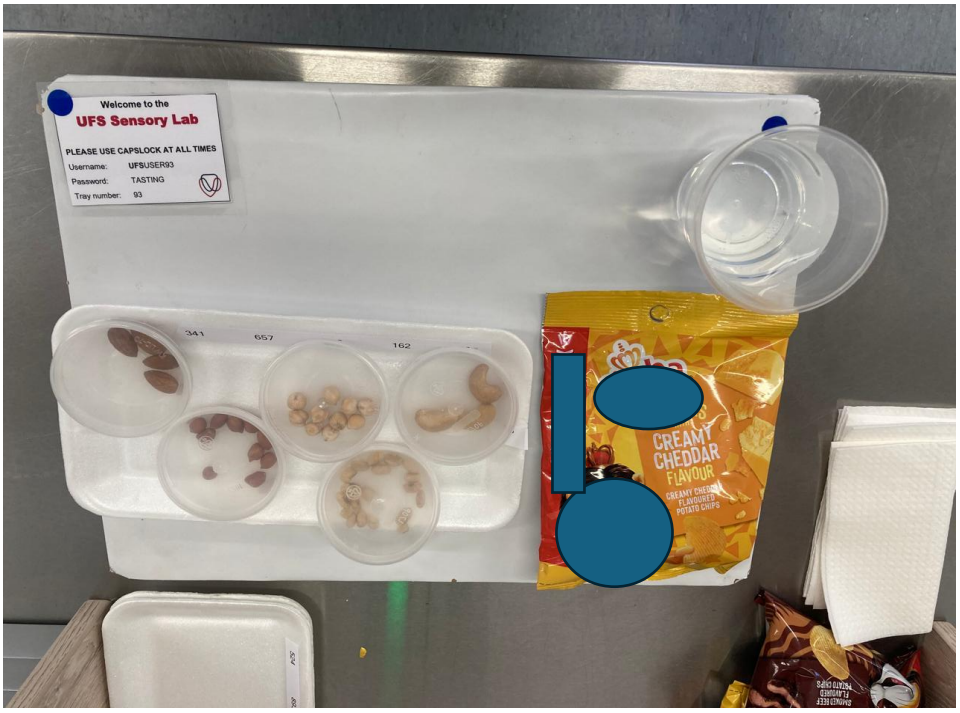

Figure 1: Serving tray for each panellist containing, from the left, almonds, peanuts, chickpeas, and soynuts

2.3.4 *Collection of demographic data*

The participants' demographic data were collected during the analysis using a questionnaire created on Evasys© software. The questionnaire contained single-answer questions, meaning the participants had to choose the one category that applied to them. The 103 participants were divided into 10 tasting sessions, where 10 participants at a time tasted and ranked all 5 samples. The sessions were scheduled at 30-minute intervals.

2.3.5 *Ethical consideration*

Ethical approval for this study was granted by the General/Human Research Ethics Committee of the UFS on the 1st of August 2024 (ethical clearance number – UFS-HSD2024/0449).

2.4 Experimental Design and Data Analysis

A combination of the Stuart-Maxwell frequency test and the McNemar test for data has been recommended to test differences between products (Gere et al., 2017). The developed snacks were assessed for acceptability using a mean overall acceptability/liking score of ≥7 on the 9-point hedonic scale, indicating high sensory acceptability (Drake et al., 2023; Zulu et al., 2023). Descriptive statistics were used to summarise the results. Mean and standard deviation values were calculated for each snack group, and frequencies were used to represent snack preferences for each snack. The differences in the overall liking assessment were determined with an analysis of variance (ANOVA). For analyses of the test, the frequency of use of each attribute was determined by counting the number of participants who used each specific attribute to evaluate the samples, from which a contingency table was created. Principal component analysis (PCA) was generated using RStudio.

3. Results

3.1 Demographic Information of the Consumer Participants

A total of 103 consumers participated in the study. The majority of the participants were female (87%), aged between 21 and 23 years (60%), and from the Black population group (92%) (Table 1).

Table 1: Demographic details of the participants undertaking the test

Information		Frequency
Age (years)	18	10
	19	13
	20	20
	21	25
	22	24
	23	11
Gender	Female	87
	Male	15
	Other	1
Home language	Afrikaans	2
	English	9
	Ndebele	2
	Northen Sotho	7
	Southern Sotho	17
	Swati	3
	Tsonga	3
	Tswana	12
	Venda	5
	Xhosa	15
	Zulu	28

3.2 Chemical Analysis of the Snack Nuts

The analysis revealed that the roasted soynuts had the highest amount of crude protein (39.608 ± 0.378 g) and neutral detergent fibre (NDF) (30.267 ± 0.200 g) compared to the other snacks (Table 2). The fat content of chickpeas was the lowest (7.278 ± 0.016 g), followed by almonds (21.114 ± 2.383 g) and soynuts (24.047 ± 0.069 g).

Table 2: Nutritional composition analysis of the roasted nut snacks used in the sensory analysis

Nutrients	Soynuts	Peanuts	Chickpeas	Almonds	Pr>F(model)
Crude protein (g/100g)	39.608 ± 0.378	30.768 ± 0.146	23.066 ± 0.016	23.296 ± 0.081	<0.0001
NDF (g/100g)	30.267 ± 0.200	28.550 ± 0.667	20.430 ± 0.120	26.239 ± 0.208	<0.0001
Fat (g/100g)	24.047 ± 0.069	46.343 ± 2.063	7.278 ± 0.016	21.114 ± 2.383	<0.0001

Note: Mean ± SD = standard deviation; $p < 0.05$ is considered statistically significant; NDF = neutral detergent fibre

The mineral and electrolyte content analysis highlighted differences in calcium (Ca), magnesium (Mg), Potassium (K), and sodium (Na) levels, respectively (Table 3). Almonds and soynuts had the highest and similar levels of Ca (0.030 mg/100 g). Moreover, almonds (0.018 mg/100 g) and soynuts (0.016 mg/100 g) had comparable levels of Mg. The electrolyte content showed that soynuts had the highest concentration of K (0.151 mg/100 g). Interestingly, all samples showed a similar amount of Na.

Table 3: Mineral analysis of the roasted nut snacks used in the sensory analysis

Minerals and electrolytes	Soynuts	AA	Peanuts	AA	Chick-peas	AA	Almonds	AA
Ca (mg/100 g)	0.030	2.736	0.005	1.282	0.014	1.712	0.030	3.382
Mg (mg/100 g)	0.016	0.373	0.012	0.303	0.010	0.294	0.018	0.201
K (mg/100 g)	0.151	1.383	0.059	0.588	0.086	1.048	0.074	0.828
Na (mg/100 g)	0.001	0.535	0.000	0.239	0.001	0.370	0.001	0.436

Note: AA = atomic absorption; Ca = calcium; Mg = magnesium; K = potassium; Na = sodium

3.2 Sensory Analysis

3.2.1 *Attributes and overall acceptability*

The results presented in Table 4 show significantly different (< 0.05) mean scores for colour, shape (appearance), aroma, flavour, texture, and overall acceptability. Peanuts had the highest mean ± SD scores for shape (7.728 ± 1.230), aroma (7.534 ± 1.539), flavour (7.544 ± 1.748), and texture (7.728 ± 1.450). Almonds had the highest mean ± SD scores for colour (7.806 ± 1.449) and texture (7.417 ± 1.785). Soynuts had the lowest mean ± SD scores for colour (4.825 ± 1.395) and shape (5.301 ± 2.071), whereas chickpeas had the lowest scores for nutty aroma (5.146 ± 1.977), flavour (3.961 ± 2.301), and texture (4.680 ± 2.402). Peanuts and almonds received the highest overall acceptability mean ± SD scores (7.728 ± 1.490 and 7.495 ± 1.771, respectively), indicating that the participants liked them very much. Meanwhile, chickpeas (4.350 ± 2.173) were slightly disliked. The participants were neutral in their ranking of soynuts (4.767 ± 2.254).

Table 4: Consumer acceptability results for the assessed roasted nut samples

Snack nuts	Colour	Shape	Nutty aroma	Flavour	Texture	Overall acceptability
Peanuts	7.680 ± 1.932	7.728 ± 1.230	7.534 ± 1.539	7.544 ± 1.748	7.728 ± 1.450	7.728 ± 1.490
Almonds	7.806 ± 1.449	7.680 ± 1.503	7.126 ± 1.929	7.350 ± 1.939	7.417 ± 1.785	7.495 ± 1.771
Soynuts	4.825 ± 1.395	5.301 ± 2.071	5.641 ± 2.218	4.660 ± 2.444	5.126 ± 2.248	4.767 ± 2.254
Chickpeas	5.359 ± 2.109	5.777 ± 2.058	5.146 ± 1.977	3.961 ± 2.301	4.680 ± 2.402	4.350 ± 2.173
Pr > F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Note: Mean ± SD = standard deviation; p < 0.05 is considered statistically significant

Figure 2 presents the results of the PCA on a biplot. PC1 (Principal Component 1), represented on the horizontal/x axis and corresponding to the first component, explains 97.5% of the variance in the data. PC2 (Principal Component 2), represented by the vertical/y axis, explains 2.1% of the variance in the data. Together, PC1 and PC2 explain 99.88% of the total variance, which is a significant proportion of the variability of the data. Each point represents an observation (nut snack sample), with the circles indicating the mean position of each nut sample type. The vectors (arrows) represent the loadings of the original variables on PC1 and PC2. The dashed circles in Figure 2 show how strongly each attribute contributes to the PCA x and y axes, and how samples are positioned relative to those attributes. As can be observed in the PCA biplot, the nutty aroma, shape, and colour vectors are more closely aligned with PC1, meaning they are more correlated with PC1, while the flavour and overall acceptability vectors are more closely aligned with PC2. Furthermore, colour and shape are more closely correlated with each other, as are overall acceptability, flavour, and nutty aroma. Simultaneously, shape and colour are negatively correlated with flavour, overall acceptability, and nutty aroma, as they point in opposite directions.

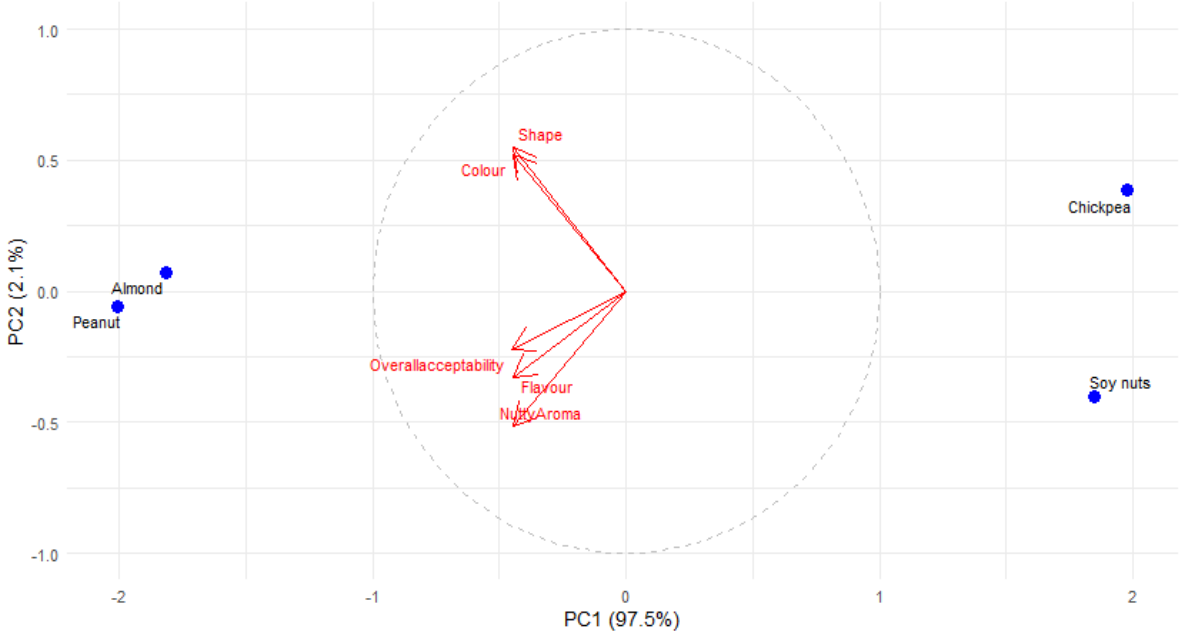

Figure 2: Principal component analysis (PCA) biplot for the assessed samples (soynuts, chickpeas, peanuts, and almonds) and the various sensory attributes

As shown in Figure 2, almonds and peanuts are clustered closely together in the PCA biplot, indicating that they share a similar liking for the assessed attributes. For instance, as shown in Table 4, almonds and peanuts scored highest across all attributes among all samples. Furthermore, the direction of the shape, colour, overall acceptability, flavour, and nutty aroma vectors further supports the latter finding, since all these vectors point towards the almond and peanut samples. In contrast, chickpeas and soynuts are relatively closer to each other. As shown in Table 4, soynuts and chickpeas received lower scores across all attributes compared to all the samples. As shown in the PCA biplot, all the vectors point away from the soynut and chickpea samples.

4. Discussion

In recent decades, South Africa has experienced a significant rise in snack consumption. This trend is a growing public health concern due to its strong association with the triple burden of malnutrition. According to a 2020 Lancet series, the consumption of inexpensive snacks and beverages has emerged as the primary risk factor for the double/triple burden of malnutrition, especially in low- and middle-income countries (LMICs), such as South Africa. A recent study conducted in South Africa has found that the most popular snacks, besides fresh fruit, consumed by socioeconomically disadvantaged communities were high in added sugar, salt, and saturated fats. It is recommended that affordable and nutritious snacks be developed to address the triple burden of malnutrition in the country (Ibiyemi & Oldewage-Theron, 2023).

This study evaluated the consumer sensory acceptability and preferences of soynuts in comparison with other popular nuts, as well as their nutritional profile, to inform the commercial development of soynuts. The study used a convenience sample of students who voluntarily participated in the study. The sample comprised more females than males, an indication that females are more likely to participate in sensory analysis studies. This is consistent with findings from research that investigated whether gender is a challenge for a sensory panel (Institute of Food Science & Technology Sensory Group , 2016). Interestingly, a recent review on the characteristics of trained sensory panels in food science found that, in most of the sensory panels, gender-balance strategies were not followed (Djekic et al., 2021). In addition, acceptance of a new food product and food preferences, such as soynuts in this study, is influenced by many factors, such as cultural background, personal attitudes, and core beliefs. Despite these influences, food selection is primarily driven by sensory attributes, namely colour, taste, aroma, and texture (Effah-Manu et al., 2023). Therefore, this study prioritised the assessment of these primary sensory drivers. There was also lower participation of students in the 18–19-year age group, who are mostly first-year students. A possible reason could be that they were still getting acclimatised to the university environment and systems. Furthermore, a small percentage (11.0%) of participants were 23 years old, an age group comprising predominantly final-year students who often face overwhelming academic projects and deadlines.

The nutritional analyses of the snack nuts showed that the roasted soynuts had the highest protein and dietary fibre content, with a lower fat content than peanuts. This is consistent with findings indicating that soy is a nutritious and affordable plant-based food source. This is characterised by its high concentration of protein, ranging from 36% to 46%, including all the essential amino acids that are beneficial for children suffering from undernutrition (wasting, stunting, and underweight). Notably, soy is also the only legume rich in both omega-3 and omega-6 fatty acids, which contribute to lowering cholesterol and cardiovascular protection (Messina, 2022), thus addressing overnutrition. Yano et al. (2024) demonstrated that a dietary snack with soybean as the main ingredient has a high-protein and low-carbohydrate content that satisfies snack consumers' appetites without compromising their dietary intakes and

health. Our study underscores the nutritional benefits of incorporating soynuts into the diet, especially in light of the triple burden of malnutrition that is prevalent in South Africa. This study observed that gender has a significant influence on the snacking behaviour among the youth.

We measured consumer participants' responses to the product stimuli, as influenced by the appearance, aroma, flavour, texture, and overall acceptability of the nuts. Based on consumer acceptability, peanuts and almonds generally had the highest scores of overall acceptability among all four samples. This was also observed for the nutty aroma and flavour of peanuts, followed by almonds, having scored higher than soynuts and chickpeas. The aroma attributes received a different ranking, where peanuts and almonds fell into a similar group and soynuts and chickpeas into another group. These trends were also observed for attributes such as snack nut flavour and texture. The lower scores and ranking of soynuts could be due to the participants' unfamiliarity with soynut snacks.

The South African nut market is experiencing a significant increase in demand, driven by a growing shift towards health consciousness and the recent emphasis on plant-based diets that favour nuts as a nutritious, convenient snack. Thus, the fact that nuts had the highest scores may be because of familiarity, as peanuts are the most consumed of all nuts in South Africa (81,496 tons annually) due to affordability (PR Newswire, 2021). Although dry-roasted soynuts are available in the country, they are produced on a small scale by local processors and health food suppliers at a cost and are thus not available in large supermarkets where the general public shops (Oja Farms, n.d.). Using soynuts as a snack is thus a new development, and there is still a limited understanding among consumers about this product category.

Food appearance and aroma strongly influence consumer preferences. Simonne et al. (2000) measured the consumer acceptability of immature soybean snacks in America, using a participant sample with comparable characteristics, with a high preference for immature soybean snacks observed. The high preference for soybean snacks among consumers in American communities may be attributed to greater awareness of the nutritional benefits and their widespread availability. Both awareness of soynut snacks and their availability are relatively low in South Africa. The mean liking scores for the sensory attributes of soynuts ranged from 5.301 to 5.641 on the 9-point hedonic scale, corresponding to the "*neither liked nor disliked*" category and indicating a need for improvement in appearance, shape, texture, and aroma. This presents an opportunity for this product to still be highly preferred and accepted among consumers. In addition, it is possible that popular nuts have improved and/or that consumers have grown slightly more accepting of them, possibly due to a greater exposure to this product category and their ready availability in the market. Our findings agree with), who reported that secondary plant metabolites in legume seeds contribute to slightly unpleasant sensory perceptions, while advances in flavour masking for plant-based products may support the development of effective strategies to reduce undesirable flavours and enhance desired ones.

Soynuts as a snack offer promising opportunities to improve sensory, nutritional, and technological aspects without relying heavily on fortification and additives. The development of flavoured soynuts could satisfy consumers' preferences for a delicious, nutritious, eco-friendly, and affordable food product. Several key considerations need to be considered for an improved soynut snack: (i) advanced plant breeding to develop new soybean grains with high-quality snack attributes, without compromising its nutritional values, (ii) improvement in the appearance, especially the shape and colour of the soynuts, to meet consumer preferences, (iii) improvement in the soynuts flavour, with varieties such as spicy, salty, butter flavour, etc.; (iv) increased awareness and availability of soynut snacks in the market; and (v) ensuring accurate labelling with an ingredients list, nutritional, allergen, and food-safety information, and sustainability footprints.

One of the strengths of this study was that it was conducted using a diverse youth population in a particular region in South Africa. While the sample was gender-skewed, the data provide a vital baseline for how the product's core physical attributes are perceived, which is the first step in determining market viability. Another limitation is the use of a convenience sample and not randomisation, as well as the fact that gender was skewed towards females. Therefore, the snacking preferences and consumption patterns may not be generalisable for all youth in South Africa. Moreover, due to logistical constraints, mineral analysis could not be conducted in triplicate; however, atomic absorbency was included to compensate for this limitation. As triplicate measurements are generally required to ensure reproducibility and statistical reliability, this represents a limitation in the dataset. To compensate for the absence of replicate mineral determinations, the AA number was included as an additional parameter. The AA number provides complementary information that strengthens the dataset and helps to contextualise the mineral composition results. While this substitution does not fully replace the robustness of triplicate mineral analyses, it offers a scientifically valid means of supporting the interpretation of compositional differences among the samples

5. Conclusion and Recommendations

Overall, this study did not clearly show that soynuts have improved sensory qualities compared to other popular nut snacks, except chickpeas. However, it presents the potential for improving the consumer acceptability attributes in soynut development and processing. This can serve as baseline data for the development of protein-based snack products and the expansion of the soynut consumer market. The findings of this study underscore the nutritional superiority of soynuts compared to other popular snacks in South Africa. The nutrient density of soynuts can contribute significantly to nutrition security in South Africa by providing a stable and reliable source of nutrient-dense snacks and improving access to safe, healthy food options, provided that consumers are aware of the nutritional and health benefits of soy.

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