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Comprehensive Evaluation of Physical, Nutritional, and Sensory Properties of Gluten–Free Instant Banana Brownie Mix

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ABSTRACT

The increasing demand for Gluten-free products has spurred interest in utilising underutilized agricultural resources such as banana flour, which also offers sustainable solutions in managing post-harvest loss. The study focused on developing a gluten-free instant brownie mix using banana flour from three varieties, namely *Ambul*, *Seni*, and Cavendish, and to analyse their physicochemical, functional, nutritional, and sensory properties. The developed brownie mix was assessed for its proximate composition, revealing a balanced nutritional profile with a notable level of dietary fibre (5.75±0.08 g/100 g) and is an energy-dense product with higher carbohydrate content (86.87±0.76 g/100 g) and lower fat content (4.50 ± 0.71 g/100 g). Highlighting higher water absorption (106.0 ± 2.83%) and oil absorption capacities (225.50 ± 0.71 %) helped to enhance the brownie's texture and moisture, especially when gluten-free. The Kraft paper zip lock packaging showed higher moisture content (3.5±0.1 g/100 g) and titratable acidity (0.00095±0.0001%) compared to high-density polyethylene packaging after nine weeks of shelf-life testing for developed brownie. The Kraft paper zip lock packaging showed higher moisture content (3.5±0.1 g/100 g) and titratable acidity (0.00095±0.0001%) compared to high-density polyethylene packaging after nine weeks of shelf-life testing. Banana brownies contain a higher carbohydrate content (5.75 ± 0.08 g/100 g), along with a notable fibre content (5.75 ± 0.08 g/100 g). In addition to promoting resource efficiency and reducing post-harvest losses, this research demonstrates the industrial potential of banana flour in developing sustainable Gluten-free bakery products.

Keywords: Banana flour, Gluten-free, Instant Brownies, Nutritional properties, Physical properties

INTRODUCTION

As a tropical perennial agricultural product, bananas are among the top 20 food commodities in the world, reaching a production of 102 megatons and corresponding to an income of US$ 28,209.5

million in 2012 (Kamalakkannan et al., 2022). In Sri Lanka, there are twenty-nine cultivable banana varieties, namely *Kolikuttu*, *Ambul*, and *Seeni Kesel*, *Suvadal*, *Embung*, *Anamalu* and etc. Abundant amounts of ripen bananas are available throughout the year since it can be grown and harvested throughout the year without any seasonal barriers (Sri Lankan Export Development Board, 2024). Due to its soft texture and high moisture content, bananas are more prone to mechanical and physical damage leading to high post-harvest loss. In Sri Lanka, it has been estimated that around 30% - 40% of the banana harvest has been lost during the post-harvesting stage (Kamalakkannan et al., 2022), which will impact the economy of the country. To overcome these post-harvest losses, different value-added products such as dried banana flour, fried banana chips, flakes, juices, jams etc. can be introduced.

Presence of gluten proteins namely gliadin and glutenin, cause negative impacts such as celiac disease and gluten sensitivity (Radünz et al., 2021).

The use of unripe banana flour as a functional, gluten-free ingredient has gained significant attention in recent years, owing to its promising physicochemical and nutritional properties (Munir et al. 2024). Numerous studies have shown that unripe banana flour serves as an excellent alternative to wheat flour in gluten-free baking applications due to its high water absorption capacity, oil-binding ability, and favorable viscosity (Bashmil et al., 2025; Mabogo et al., 2021; Mendis et al., 2025). These attributes contribute to improved texture and moisture retention in baked products. Additionally, unripe banana flour is naturally abundant in dietary fiber, resistant starch, and bioactive compounds such as phenolics and vitamin C, making it a nutritionally superior substitute that supports gut health and helps regulate glycemic levels (Munir et al. 2024). In terms of sensory acceptance, past research has indicated that gluten-free products made with unripe banana flour can achieve satisfactory taste, texture, and overall consumer acceptability when compared to traditional wheat-based options (Mashau et al. 2024). Therefore, the potential of unripe banana flour in developing gluten-free instant formulations is both scientifically validated and practically feasible, effectively addressing the nutritional and sensory needs of gluten-sensitive consumers. In addition, banana flour contains bioactive substances such as carotenoids, flavonoids, and phenolic acids that have anti-inflammatory and antioxidant properties (Sidhu & Zafar, 2018).

Despite its notable nutritional and functional benefits, the use of unripe banana flour as a key ingredient in gluten-free instant mixes remains underexplored. Although rich in resistant starch, dietary fibre, and bioactive compounds, its incorporation into ready-to-use gluten-free products has attracted limited scientific attention. Addressing this gap is crucial not only for fostering product innovation but also for increasing the economic value of surplus banana harvests, particularly in tropical countries like Sri Lanka.

Therefore, this study aims to develop a gluten-free instant brownie mix using unripe banana flour and assess its potential as a functional, health-oriented alternative to conventional wheat-based products. A comprehensive evaluation of its physical, nutritional, functional, sensory, and shelf-life properties was conducted. By targeting these quality attributes, the research seeks to promote value addition as a means of reducing post-harvest loss of banana, while meeting the rising demand for convenient gluten-free bakery products in both local and global markets.

MATERIALS AND METHODS

Preparation of banana flour

Three varieties of Musa spp. (*Ambul* banana, *Seeni* banana and Cavendish banana) in the first stage of ripening were used in preparation of the banana flour separately. In briefly, banana fingers were washed, cut in to similar-sized pieces (3 mm), and the cut pieces were dipped in 0.5% citric acid solution. After draining, the banana pieces were dehydrated at 60 °C for eight hours, and then the dried banana pieces were grinded and sieved to produce banana flour (Fatemeh et al. 2012).

Preparation of gluten-free instant banana brownie mix

Main ingredients

Banana flour (*Ambul Seeni* and Cavendish banana), cocoa powder, vanilla powder, instant coffee, brown sugar, and white sugar were purchased from the local market.

Preparation of gluten-free instant brownie mix

All the ingredients were weighed according to the required amounts, and they were ground and mixed together until the mixture became homogeneous. The mixture was sieved to remove the larger particles, and thereafter, the three separate brownie mixes were taken for further analysis.

Analysis of physical and nutritional properties of three different gluten-free instant brownie mix

Bulk density (BD)

BD was determined according to the method described in Osei Tutu (2024). Briefly, fifty grams of each banana brownie mix (M) were weighed and gently poured through a glass funnel into a 100 mL cylinder. The volume occupied by the sample was recorded (V_0), and the bulk density was calculated using following Equation.

$$Bulk\ Density\ = M/Vo$$

Tapped density (TD)

Tapped density was calculated using the tapped volume (Vf) obtained after tapping the measuring cylinder on a flat tabletop surface twenty times after adding a known weight of the sample (M) (Bala et al., 2020).

$$Tapped\ Density\ = M/Vf$$

Compressibility index (CI) and Hausner ratio (HR)

Using both BD and TD, the compressibility index and the Hausner ratio were calculated by using following equations (Milovanovic et al., 2020).

$$HR = Td\ /\ Bd$$

$$CI = \ [((Td - Bd))\ /\ Td] \times 100$$

Water absorption capacity (WAC) and oil absorption capacity (OAC)

WAC and OAC were assessed by using the method described in Osei Tutu et al., (2024) with slight adjustments. One gram of the sample was submerged in ten millilitres of distilled water or oil and left to settle in a centrifuge tube for 30 minutes, after which it was centrifuged at 2300 rpm for 25 minutes. WAC and OAC were displayed as grams of absorbed weight of water or oil per gram of the sample, respectively.

Foaming capacity (FC)

FC was measured according to the method described by (Osei Tutu et al., 2024) with some modifications. One gram of the sample was added to 50 mL of distilled water and the suspension was mixed vigorously for two minutes. The volume before and after whipping was recorded and the FC was calculated.

Swelling capacity (SC)

The SC of each instant brownie mix was measured as described by Osei Tutu et al., (2024), where each brownie mix was added up to the 10 mL mark in a 100 mL graduated cylinder and tapped at the bottom. Then Water was added up to 50 mL, and the content was mixed by inverting the cylinder after covering its top. The suspension was inverted again after two minutes and was allowed to stand for 30 min. The volume occupied by the sample was taken after 30 min, and the values were recorded. SC was calculated by using following equations.

$$SC = \frac{volume\ after\ sweling - volume\ before\ swelling}{weight\ of\ the\ sample}$$

Transparency

An aqueous solution was prepared by mixing one gram of the instant brownie mixture with 99 g of water. The prepared solution was kept in a boiling water-bath for 15 min under continuous stirring. After cooling, the transparency of the solution was measured at 620 nm using the spectrophotometer (CT-8600 double beam spectrophotometer-Spain) (Wang et al., 2017).

Gelatinization temperature (GT)

One gram of each sample and 10 mL of distilled water were added into a screw-capped tube and the mixture was heated slowly in a water bath until they formed a solid gel. The temperature at the point of complete gel formation, was recorded as the GT (Chandra and Samsher, 2013).

Color analysis

The color was determined by using a colorimeter (BIOBASE, BC-110/200, China) according to CIE color system. L*, a*, and b* values were taken in semi-dark conditions. Chroma (ΔC), hue angle (H_{ab}), Yellowness index (YI) and whiteness index (WI) were calculated according to following Equations (Hirschler, 2012).

$$Chroma\ (\Delta C) = \sqrt{(a)^2 + (b)^2}$$

$$Hue\ angle\ (H_{ab}) = tan^{-1}\,(b/a)$$

$$(YI) = \frac{142.86\, b}{L}$$

$$(WI) = 100 - \sqrt{(100 - L^2) + a^2 + b^2}$$

Vitamin C

Two grams of the sample was mixed with 100 mL of distilled water, and the mixture was filtered. Five millilitres of the filtrate was taken and volumed up to 100 mL with distilled water. After adding phenolphthalein indicator, and the mixture was titrated with 0.01N NaOH until the color of the solution turned into pink. The vitamin C content in 100 g of the sample was calculated using the following Equation (Ndayambaje et al., 2019).

$$Vit.C = \frac{(Vol.NaOH \times 0.01\ N \times 100ml \times 100g \times 176.13 \times 10^{-3})}{2}$$

Selection of the best banana-based instant brownie mix

A panel of 30 semi-trained panelists was used for the sensory evaluation. Colour, smell, taste, texture and overall acceptability were analyzed using 5-point hedonic scale. According to the results of the sensory analysis, the most suitable product was selected for further studies. During the sensory evaluation, the prepared brownie samples were presented under normal lighting conditions under ambient temperature in three separate paper plates labelled with random three-digit numbers.

Determination of nutritional composition and shelf life of selected gluten-free instant brownie mix

Proximate composition of the selected sample was determined according to the AOAC, (2019) standard methods as follows; moisture (AOAC 934.15), ash (AOAC 942.05), crude protein (AOAC 2001.11), crude fat (AOAC 2003.05), crude fibre (AOAC 978.10) was determined according to the AOAC (2019) standard methods. Total carbohydrate content was determined by subtracting the sum of all other contents by 100 g.

Shelf-life of the selected gluten-free instant brownie mix

Both high-density polyethene packages (HDPE) and Kraft paper zip lock bags were used as packaging material and the following parameters were tested to determination of the self-life of the developed product for 60 days under normal room temperature conditions and the best packaging material was selected. Moisture was determined according to AOAC 934.15 (2019). Titratable acidity was assessed in accordance with the methodology established by Osei Tutu (2024). pH determination was done using portable pH meter (Model AD 132, Rumania), where the suspension of the brownie mix at a concentration of 10% (w/v) was allowed to stand for 30 minutes then the filtrate was used to determine the pH. The color was measured according to the CIE color system using a colorimeter (BIOBASE, BC-110/200, China), and the L*, a*, and b* values were taken under semi-dark conditions. Hue angle (H_{ab}), Yellowness index (YI) was calculated using above mention equations. Total plate count and Yeast and mold count were determined according to the method described in Ali (2023).

Statistical analysis

All results were presented as mean ± standard deviation and readings were taken in triplicates (n=3). One-way ANOVA was applied and the level of significance was set at $p<0.05$ (confidence level = 95 %) for physico-chemical and nutritional properties among the three gluten-free instant brownie mixes. Data obtained from the sensory evaluation were analysed using the Kruskal Wallis nonparametric method. All statistical analyses were done using the MINITAB 20 statistical software for Windows and all sensory data was analysed using Statistix 10 software.

RESULTS AND DISCUSSION

Physico-functional properties of gluten-free instant banana brownie mixes

Three different gluten-free instant brownie mixes were prepared using the different types of banana flour separately, and their physico-functional properties were analysed, and the obtained results are summarized in Table 1. In the food industry, the bulk density (BD) and the tapped density (TD) play a crucial role in determining the requirement for packaging and material handling. It is important in processing, storing, transporting and formulating of dry powders. Also, it is important in determining the flowability of powders that affects the storage, final quality and the texture of the baked products. According to Suhag (2024), higher BD and TD can generally indicate lower flowability in a martial. Highest value for bulk density was observed from the Gluten-free brownie mixes made out of *Seeni* banana flour (0.51± 0.10 g/mL). However, according to the results in Table 1, there was no significant difference ($p>0.05$) observed for both bulk and tapped densities of the developed brownie mixes. As reported by Alam et al. (2023) BD and TD of bakery products made out of banana flour can range from 0.51 to 0.81 g/mL and 0.62–0.93 g/mL, respectively. The results of the present study showed that all the developed banana flour brownie mixes fall within the acceptable range of bulk density. In addition, the study highlighted that bulk density can vary depending on factors such as the banana cultivar, drying method, and particle size of the banana flour.

The sequence of the variation in the tapped density among the three tested brownie mixes was in the order of *Ambul*, *Seeni*, and Cavendish. Both Compressibility Index (CI) and Hausner Ratio (HR) are used to measure the flow characters of flour products. Higher values of CI and HR indicate more cohesiveness in flour, which leads to bridging, discharge problems, and improper flow in product development (Bala et al. 2020). There was a significant difference (p<0.05) between *Ambul* and Cavendish brownie mix, as well as between *Seeni* and Cavendish brownie mix for both CI and HR. This may be due to the particle size and shape difference of the varieties. *Ambul* banana-based instant brownie mix showed the highest values (CI-39.02±1.05, HR-1.64±0.03) and Cavendish based instant brownie mix showed the lowest values (CI-34.41±0.29, HR-1.52±0.01) for CI and HR. With higher values of CI and HR, *Ambul* banana-based instant brownie mix may indicate more cohesiveness with low flow properties in the final product while Cavendish-based instant brownie mix demonstrate comparatively lower cohesiveness with higher flow properties. Previous studies suggested that both CI and HR of banana flour incorporated baked products typically fall within the ranges of 9.38 – 13.58% for CI and 1.1 to 1.30 for HR (Etti et al., 2019). These differences may be primarily attributed to variations in the particle size of the banana flour used. Additionally, as reported by Etti et al. (2019), higher levels of resistant starch in ripened banana flour can lead to increased CI and HR values, mainly due to its higher moisture content and water absorption capacity. The findings of the present study also support these results by demonstrating a higher water absorption capacity (Table 1).

Swelling capacity indicates the measure of the ability of starch to absorb water and swell. In a gluten-free product, high SC is very important as it compensates for the structural and moisture retention properties that are typically provided by gluten. High SC in gluten-free flours like banana flour, enhances water absorption and improves the product texture, and softness which are often challenging characteristics to achieve without gluten (Šmídová and Rysová 2022). Compared to the other two brownie mixes, the brownie mix made with *Ambul* banana showed significantly highest SC (10.00 ± 0.01 g/mL) indicating that it is more suitable for producing Gluten-free products. SC of banana flour incorporated baked product can range from 1.73 to 13.5 g/mL as reported by Hasmadi et al. (2021).

Transparency of the brownie mixes prepared using various banana varieties significantly differs (p<0.05) from one another, where the Cavendish instant banana brownie mix showed the significantly highest transparency compared to *ambul* and the *seeni* brownie mix. This may be due to the variations in solubility and L*, a*, and b* color parameters.

Water absorption capacity (WAC) and oil absorption capacity (OAC) are the key properties in the bakery industry due to their significant impact on dough handling, texture and mouthfeel of the final product. High WAC enables key attributes of a flour such as to retain the moisture, improve the softness and freshness in bakery foods. With the incorporation of fat, OAC contributes flavour retention and tender crumb that enhances the mouthfeel. In Gluten-free products, both WAC and OAC are particularly critical, as they help to compensate for the moisture binding and help in texture improvement, which is facilitated by gluten (Hasmadi et al. 2020). According to Rani and Badwaik (2021) WAC in Gluten-free products improves the dough elasticity and cohesiveness, while OAC helps to mimic the rich mouthfeel and flavour traditionally given by gluten. As per the results in Table 1, brownie mix made from Cavendish and *Ambul* banana demonstrated significantly highest WAC (118.50 ± 2.12%) and OAC (237.00 ± 1.41%), respectively, facilitating more elasticity and cohesiveness to the final product, and thus, improving the texture and the mouthfeel. Along with that, the developed Gluten-free instant banana brownie mix will facilitate the production of high-quality, appealing Gluten-free bakery items, essentially for in the gluten-intolerant market segment (Kaur et al. 2015; Šmídová and Rysová 2022). According to previous research studies, WAC and OAC of the banana flour can vary from 165.8–170.1% and 132.6–168.1%, respectively (Miah et al. 2023). When comparing the developed banana flour brownie mixes, *Ambul* and *Seeni* flour-incorporated mixes exhibited slightly higher oil absorption capacity (OAC). This variation may be attributed to compositional differences between the banana flours. However, all water absorption capacity (WAC) values remained within the range reported in previous studies.(Miah et al. 2023).

The chroma, hue angle, whiteness index (WI), and yellowness index (YI) together with the CIE L*, a*, and b* color parameters are also summarized in the Table 1. Cavendish brownie mix showed significantly higher (p<0.05) a* value demonstrating more redness, while significantly higher (p<0.05) b*, L*, hue angle and YI value were observed in the brownie mix made with *Ambul*. The hue angle gives relative amount of redness and yellowness, while YI shows the degree of yellowness, and since *Ambul* brownie mix showed higher values for both hue angle and YI, we can conclude that its color is more towards yellowness. These indices will be helpful in monitoring the correct formulation in food industry, where color consistency can be used as a key parameter for quality, freshness and proper texture.

Nutritional properties of Gluten-free instant brownie mixes

When consider the vitamin C content, there were no significant differences in vitamin contents among banana varieties, but *Ambul* (11.76 ± 0.19 g/100 g) banana-based instant brownie mix showed the highest vitamin C content followed by *Seeni* (11.54 ± 0.12 g/100 g) and Cavendish (11.32 ± 0.06 g/100 g) instant brownie mixes. Vitamin C in the raw *Ambul, Seeni and* Cavendish bananas are in the range of 16.6 mg/100 g to 18 mg/100 g by highlighting higher values in Cavendish (18.1mg/100 g) and *Ambul* (17.9 mg/100 g) with slightly low value in *Seeni* (16.5 mg/100 g) (Nadeeshani et al., 2021; Opara et al., 2013). But this slight reduction of Vitamin C in the instant brownie mix may be due to the use of high heat (60 °C) when preparing banana flour (Alam et al. 2023).

Evaluation of sensory properties of three types of banana brownies from gluten-free brownie mix

Sensory analysis is crucial in determining the consumer perception of a newly developed food product. Thus, the three distinct instant brownie mixes made from three types of bananas were evaluated organoleptically, and the best brownie recipe was chosen. Table 2 presents an overview of the mean rank values of the studied sensory attributes.

Results of the sensory evaluation showed that there is no significant difference (p>0.05) among the tested treatments. This may be due to the use of same baking conditions, same recipe except for the type of flour and same baking time to develop all three types of instant brownies. However, the Gluten-free brownies made from S*eeni* banana mix was able to secure the highest mean rank values for all the tested sensory attributes, and was selected as the best brownie mix for further analysis. The obtained results were compared with those of brownies made from wheat flour that were reported in past research work (Sumartini et al. 2021**;** Lubis et al. 2021)**.**

Nutritional and sensory evaluation of a selected banana flour-incorporated gluten-free product with wheat flour-incorporated product

Nutritional comparison

Comparison of the results of the proximate analysis of the selected brownies made with *Seeni* banana flour was compared with those of wheat flour (Sumartini et al. 2021**;** Lubis et al. 2021) are summarized in the Table 3. As per the results, the gluten-free brownies showed lower moisture content (1.70 ± 0.14 g/100 g) that enhanced its shelf life by minimizing their microbial growth and enzymatic activities. Additionally, the higher ash content of banana-based Gluten-free brownies reflects a richer mineral profile, which may support bone health and metabolic functions. Lower crude fat content in banana-based Gluten-free brownies offers a lower-calorie option, which may be beneficial for weight management and heart health by reducing saturated fat and cholesterol intake. However, lower protein content and the absence of gluten proteins, like gliadin and glutenin, limit the structural properties but make the product suitable for individuals with celiac disease or gluten intolerance, which is one of the main objectives of this study. Protein enrichment through nuts, legumes or plant-based protein isolates can address these limitations while preserving the Gluten-free nature of the product. Also, higher carbohydrate content in banana brownies indicates it give more energy dense source, compared to wheat flour-based brownies, and ideal for physically active individuals. Additionally, since banana flour is rich in resistant starch, it promotes the gut health by acting as a prebiotic and improving glycaemic control. Further, with the notable amount of fibre content of this product, beneficial in producing favourable microbial metabolites such as short chain fatty acids, while helping to prevent obesity, diabetes and other metabolic disorders while maintaining well the health of the gastrointestinal system (Chen et al. 2024; Fu et al. 2022). According to the previous studies that have developed banana flour incorporated baked products, proximate analysis results fall within the following ranges: moisture content 6.2–35.7 g/100 g, crude fat 0.4–4.01 g/100 g, crude protein 1.7–8.01 g/100 g, crude fiber 1.07–3.43 g/100 g, crude ash 1.21–2.02 g/100 g, and total carbohydrates 50.90–69.49 g/100 g (Ayo-Omogie and Odekunle 2017; Rahman et al. 2021). Comparison of the observed data with the best-performing brownie mix shows that crude fat, protein, and fiber contents fall within the ranges reported in previous studies, demonstrating alignment with existing findings. However, the moisture content was found to be lower than values reported in earlier research. This reduction is likely due to the higher drying temperature (60 °C) used during banana flour preparation, which enhanced water removal and contributed to lower moisture levels. The selected temperature also aimed to improve product shelf life. Furthermore, Cheok et al. (2018) reported that unripe bananas possess lower moisture content compared to fresh ripe fruits.

Sensory evaluations

Further, the sensory acceptance of the *Seeni* banana brownie was compared with that of wheat flour brownies and the obtained results are summarized in Table 4. According to the findings, there were no significant differences ($p > 0.05$) between the two types of brownie products for all the tested sensory attributes. This indicates that the newly developed brownies are equally acceptable to consumers when compared with commercially available product made from wheat flour. Although no significant differences ($p > 0.05$) were found in terms of flavour, aroma, and color, the wheat flour-incorporated brownies received the highest likability scores. However, when considering overall acceptability and preference, the newly developed gluten-free brownies made with banana flour received the highest mean rank.

Evaluation of the shelf-life of *Seeni* banana-based instant gluten-free brownie

The variation in microbial count, pH level, moisture content, titratable acidity and color difference of the selected instant brownie mix was examined under normal room temperature conditions for nine-weeks period using two different packaging materials namely HDPE and Kraft paper zip lock bags. All the analysed data have been summarized in Table .

The moisture content of the selected best instant brownie mix has slightly increased during the storage period of 9 weeks (Table 5). However, there was no significant difference ($p>0.05$) between the packaging materials (HDPE and Kraft paper zip lock bags) for moisture changes. Moreover, the moisture content of the instant brownie mix was found to be within the safe limit, where it was 15.5% for packed wheat flour (Codex Alimentarius, 1985). The increment in the moisture content throughout the storage period may be due to a result of the equilibrium of the vapour pressures inside the packaging and dependent on the rate of water vapour permeability of the packaging materials. As reported by Pragati et al. (2014), the moisture content of unripe banana flour-incorporated products changed by 2.18 g/100 g from the initial day up to 60 days of storage. This observation closely aligns with the moisture content changes recorded in the present study during the storage period. One of the major functions of packaging material is to act as a barrier against moisture, water vapour, light, and any form of contamination. However, the packaging materials used in the present study (HDPE and Kraft paper zip lock bags) partially provided the aforementioned barrier properties and may cause to increase in the moisture content of the product.

A slight decline in pH was observed (Table 5). in the banana brownie mixes stored in HDPE and Kraft paper zip lock bags over the 9 weeks can be attributed to microbial activity and the biochemical conversion of sugar into minor alcohols and organic acids, which may be natural byproducts of fermentation or microbial metabolisms. During storage even in a sealed package, microbial activity can lead to the production of these by-products and can lower the pH. This change is not significant ($p>0.05$), as the pH values (ranging from 5.94 to 6.37) remained with an acceptable pH range for wheat flour-based products (6.0-6.8) as reported by Milkias et al. (2024). The pH value of the Gluten-free brownie remained consistent with the recommended range, suggesting that the product maintained its quality during the storage, with minor pH decline indicating normal, controlled microbial activity rather than spoilage.

The color of the final product may affect consumer perception towards the food. As shown in the Table 5 at the end of the storage period, L*, a* and b* colour values YI, h_{ab} instant banana brownie mix packed in both types of packages were lower than values shown at beginning of the storage. These colour changes in the mix may be due to the storage temperature and colour changes in cocoa powder with the storage time. As reported by Pragati et al. (2014), the L*, a*, and b* color values of unripe banana flour-incorporated products changed by 1.01, 0.09, and 1.40, respectively over a 60-day storage period. These changes closely correlate with the findings of the present study.

When compared to the mix in Kraft paper bags, the instant banana brownie mix stored in HDPE packaging showed a modest rise in titratable acidity Table 5. This can be attributed to a number of variables, including the permeability of the packing material and possible microbial activity. Since HDPE's increased permeability to moisture and gasses like oxygen, microbes like yeast or bacteria may thrive in the microenvironment it creates inside the packaging. Over time, the titratable acidity will rise as a result of these bacteria' ability to convert carbohydrates into organic acids. After the third week, there was an increase in acidity in the brownie mix packaged in HDPE, but it was mostly unchanged after that. The Kraft paper bags, on the other hand, offered a better-regulated environment, restricting microbial development and maintaining the titratable acidity throughout the storage time due to their reduced moisture and oxygen permeability. As a result, even though the HDPE container permitted some microbial activity and a small amount of acid generation, the brownie mix's quality was not considerably lowered, indicating that its shelf life was still good. Kraft paper bags, on the other hand, might have been better at halting microbial contamination and maintaining the acidity and overall quality of the food. Though each type of packaging had advantages, the HDPE packaging's small rise in acidity suggests that the mix was essentially unaffected and showed little signs of spoiling during storage. Rahman et al. (2014) stated that titratable acidity (TA) generally shows a slight increase during storage, which aligns with the current study's findings, although the increase was observed at a lower rate. The study also noted that such changes can vary depending on factors such as product formulation and the specific type of banana flour used.

The microbiological stability of the instant Gluten-free brownie, as evidenced by the absence of TPC and Yeast and Mold count (0 CFU/g) over the storage period of the study, highlights its safety and quality without any preservatives. Despite increased moisture content level during storage and varying temperature, the product maintained its microbiological integrity. These results can be attributes of good hygiene practices during the preparation and especially the lower moisture content of the brownies which restricts the metabolic activities of the spoilage and pathogenic microorganisms, and thereby enhancing the product shelf-life.

CONCLUSION

The present study developed gluten-free instant brownie mixes using *Seeni, Ambul*, and Cavendish banana flours. Among them, *Seeni* banana flour showed the best functional and sensory properties, making it most suitable for instant brownie mix formulation. Nutritionally, *Seeni* banana-based brownies showed significantly higher levels of dietary fiber, vitamin C, ash, and carbohydrates compared to wheat-based brownies, making them a healthier, energy-rich alternative. These findings highlight the potential of *Seeni* banana flour in gluten-free bakery product development. The research also promotes value addition to surplus bananas, offering sustainable solutions to reduce post-harvest losses and enhance food product innovation.

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Table 1. Physico-functional properties in three different Gluten-free instant brownie mixes

Physical Property	*Ambul*	*Seeni*	Cavendish
BD (g/mL)	0.50± 0.10[a]	0.51± 0.10 [a]	0.51±0.01 [a]
TD (g/mL)	0.82± 0.02 [a]	0.785± 0.01[a]	0.77±0.01 [a]
CI %	39.02 ± 1.05 [a]	35.03 ± 0.59 [b]	34.41 ± 0.29 [b]
HR	1.64 ± 0.03 [a]	1.54 ± 0.01 [b]	1.52 ± 0.01 [b]
SC (mL/g)	10.00 ± 0.01 [a]	7.25 ± 0.35 [b]	8.50 ± 0.71 [ab]
Transparency	5.30 ± 0.00 [c]	6.90 ± 0.00 [b]	7.20 ± 0.00 [a]
WAC %	118.50 ± 2.12 [a]	106.00 ± 2.83 [b]	129.50 ± 3.54 [a]
OAC %	237.00 ± 1.41 [a]	225.50 ± 0.71 [a]	172.50 ± 0.71 [b]
L*	24.27± 0.05 [a]	22.18 ± 0.06 [b]	22.40 ± 0.04 [b]
a*	10.30 ± 0.01 [c]	15.43 ± 0.29 [b]	17.29 ± 0.07 [a]
b*	5.66 ± 0.05 [a]	2.89 ± 0.74 [b]	3.09 ± 0.04 [b]
Hue angle	0.50 ± 0.00 [a]	0.18 ± 0.04 [b]	0.18 ± 0.00 [b]
YI	107.67 ± 0.31 [a]	47.89 ±11.73 [c]	55.82 ± 0.59 [b]
WI	6.76 ± 0.15 [b]	7.27± 0.10 [a]	6.24 ± 0.02 [b]
Chroma	15.47 ± 0.22 [a]	9.18 ± 0.05 [a]	12.60 ± 0.04 [b]

Values in the same rows followed by different superscripts are significantly different at ($p<0.05$); each value represents the mean ± SD of three replicates

Table 2. Mean rank values of three different types of instant brownie mix prepared using banana

Brownies type	**Texture**	**Taste**	**Aroma**	**Color**	**Appearance**	**Overall acceptability**
Ambul Banana	43.83±0.61[a]	46.57±0.63[a]	45.73±0.91[a]	40.60±0.77[a]	47.25±0.81[a]	46.43±0.67[a]
Seeni Banana	48.93±0.73[a]	50.47±0.63[a]	50.37±0.72[a]	53.48±0.56[a]	48.77±0.63[a]	50.23±0.68[a]
Cavendish Banana	43.73±1.05[a]	39.47±0.99[a]	40.40±0.85[a]	42.42±0.90[a]	40.48±1.01[a]	39.83±0.88[a]

Results mean ranks with the same superscript within the same column are not significantly different from each other at ($p >0.05$)

Table 3. Proximate composition of best instant gluten-free brownies (Seeni banana flour) and brownies from wheat flour

Component	Brownies from Gluten-free Brownie mix (g/100 g)	Brownies from wheat flour (g/100 g)
Moisture content	1.70 ± 0.14	18-37
Ash content	1.80 ± 0.28	0.8-1.4
Crude fat	4.50 ± 0.71	21- 23
Crude protein	0.96 ± 0.01	4 – 4.5
Crude fiber	5.75 ± 0.08	13-14
Carbohydrate	86.87 ± 0.76	40-50

Comparison of nutritional profile between selected best instant Gluten-free brownies (Seeni banana flour) and brownies from wheat flour (Sumartini et al. 2021; Lubis et al. 2021)

Table 4. Mean rank of the sensory evaluation between brownies made out of banana flour and wheat flour

Product Type	Texture	Flavor	Aroma	Colour	Appearance	Overall acceptability	Preference
Brownies (Wheat flour)	30.6[a]	32.1[a]	31.3[a]	31.38[a]	30.3[a]	33.1[a]	30.5[a]
Developed gluten-free brownies (Seeni banana)	30.7[a]	28.9[a]	29.7[a]	29.17[a]	30.7[a]	33.5[a]	31.5[a]

Results are means ranks with same superscript within the same column are not significantly different from each other at (p >0.05)

Table 5. Evaluation of the shelf-life of *Seeni* banana-based instant gluten-free brownie

Parameters	Packaging materials	Storage time (Weeks)				
		1 week	3 weeks	5 weeks	7 weeks	9 weeks
MC(g/100g)	HDPE	2.5 ± 0.5	2.6 ±1.2	2.65 ± 2.0	2.9 ±0.7	3 ±0.5
	Paper (zip lock)	2.5 ± 0.9	2.7 ±0.6	2.75 ±1.2	3.2 ±0.5	3.5 ± 0.1
pH	HDPE	6.35±0.2	5.98±0.6	6.15±0.8	6.05±0.6	6.08 ± 0.5
	Paper (zip lock)	6.35 ±0.5	6.1 ± 0.5	6.19 ±0.6	6.08 ±0.8	6.09 ± 0.7
L*	HDPE	6.2 ±0.6	7 ±0.3	7.8 ±1.0	6.8 ±0.2	6.1 ± 0.7
	Paper (zip lock)	6.3 ±0.4	7 ±0.5	7.1 ±1.2	6.5 ±0.5	5.9 ± 0.8
a*	HDPE	9.8 ±0.3	10 ±1.2	10.3 ±0.8	10 ±3.1	9.8 ± 1.2
	Paper (zip lock)	10.5 ±0.5	10.5 ±0.9	10.3 ±0.7	10.7 ±2.5	9.5 ± 1.4
b*	HDPE	2.5 ±0.1	2.6 ±0.6	2.8 ±0.4	2.5 ±0.6	2 ± 0.8
	Paper (zip lock)	2.5 ±0.3	2.6 ±0.8	2.6 ±0.6	2.4 ±0.5	1.8 ± 0.9
Hue angel	HDPE	180.24 ±3.5	180.26 ±3.5	180.25 ±4.2	180.24 ±4.5	180.15 ±2.3
	Paper (zip lock)	180.3 ±4.2	180.28 ±4.2	180.27 ±3.2	180.25 ±5.6	180.21 ±2.1
YI	HDPE	63 ± 2	56 ± 5	54 ± 4	55 ±5	49 ± 2

	Paper (zip lock)	59 ± 3	52 ± 3	51 ± 3	50 ±4	29 ± 4
Titratable acidity	HDPE	0.00065 ± 0.0001	0.00077 ± 0.0001	0.00091 ± 0.0001	0.00091 ± 0.0001	0.00091 ± 0.0001
	Paper (zip lock)	0.00085 ± 0.0001	0.00087 ± 0.0001	0.0009 ± 0.0001	0.00094 ± 0.0001	0.00095 ± 0.0001