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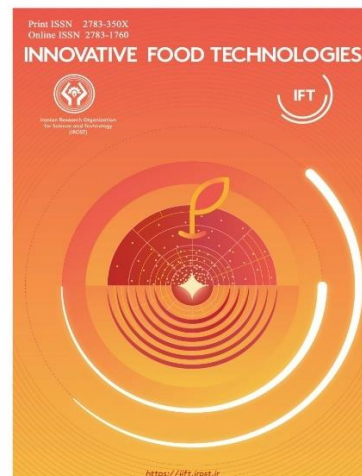
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Development of an alternative composite jackfruit, pumpkin, and green banana flour-based sandwich snack with a moderate predicted glycemic index

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Abstract:

Jackfruit, pumpkin, and green banana are alternative flour sources with potential for use in the bakery industry, helping overcome the drawbacks of traditional wheat flour and improving the nutritional value of snack foods. The use of composite flour appears to be a promising approach for bakery products, substituting for wheat flour while preserving consumer acceptability. This study formulated a composite sandwich snack using jackfruit (*Artocarpus heterophyllus*), pumpkin (*Cucurbita maxima*), and green banana (*Musa acuminata*) flours blended with wheat flour. Flours were prepared by hot-air-drying at 60°C. Proximate analysis revealed pumpkin flour contained 8.75% crude fiber, while jackfruit flour had 4.86% protein. Banana flour exhibited the highest Total Phenolic Content at 0.81 mg GAE/g, whereas pumpkin flour showed the greatest Total Flavonoid Content at 1.77 mg QE/g. Sensory evaluation by a trained panel determined that the optimal Formulation comprised 30% jackfruit, 15% pumpkin, and 25% green banana flour layers, combined with an oyster (*Pleurotus ostreatus*) mushroom filling (selected from separate, single-flour sensory optimizations rather than a simultaneous three-component comparison; see Section 3.5). The final developed snack yielded an impressive 10.31% crude protein, 6.18% crude fat, 8.16% dietary fiber, 42.82% carbohydrate, and 264.14 kcal/100g on a dry-weight basis. The snack also displayed significant antioxidant capacity, with TPC of 0.31 mg GAE/g, TFC of 0.112 mg QE/g, FRAP of 0.06 mg TE/g, and DPPH half-maximal inhibitory concentration (IC₅₀) of 318 ± 102 µg/mL. In vitro starch digestibility testing resulted in a predicted Glycemic Index(pGI) of 68.11, categorizing the formulated composite sandwich as an intermediate-pGI food (56–69 range). The snack is not gluten-free, as it retains a majority wheat-flour base; it offers a nutrient-dense, fibre-rich alternative for the bakery sector, although the predicted GI is based on an in vitro assay and requires clinical validation before health claims are extended.

Keywords: Jackfruit flour, Pumpkin flour, Green banana flour, Oyster mushroom, Predicted Glycemic Index, Ferric Reducing Antioxidant Power

1. Introduction

Snacks are convenient foods that can be easily accessed and are typically eaten between traditional mealtimes to promote satiety and suppress overconsumption at subsequent meals (Kahiya et al., 2016). Dietary patterns have shifted towards snacks due to rapid urbanization, changing lifestyles, busy schedules, and increased access to processed foods. In recent years, demand for snack foods has grown rapidly (M. A. Brennan et al., 2012). Snacks are very popular among all age groups and significantly contribute to daily nutrient requirements. Snacks often replace conventional meals, and the tendency to have a snack thereby skips a meal during the day (Crofton et al., 2013). The dietary concerns of today's population, driven by changes in food consumption patterns that lead to fast-paced lifestyles, are facilitated by the availability of nutritious, affordable, palatable, and easily consumed convenience foods, such as snacks (Momanyi et al., 2019). Diets have been suppressed by various unhealthy snack options, with rising concern about health. Poor consumer awareness of snacks primes for undesirable health links between energy-dense foods and diet-related diseases, such as non-communicable diseases, and poses an economic burden on the country. Therefore, the snack industry has endeavored to improve the nutritional content of snacks by incorporating fruits, vegetables, and alternative flours, which provide bioactive phytochemicals and dietary fiber.

The glycemic index (GI) is a physiologically grounded ranking of carbohydrate-containing foods according to the rise in blood glucose they produce relative to a reference food. Diets dominated by high-GI foods provoke repeated post-prandial hyperglycaemia and compensatory hyperinsulinaemia; over time this pattern is associated with peripheral insulin resistance, beta-cell strain, and a pro-inflammatory, dyslipidaemic metabolic profile (Ludwig, 2002), (Livesey et al., 2018). Epidemiological cohort studies have linked habitual consumption of low- and medium-GI carbohydrate sources with a reduced risk of type 2 diabetes, cardiovascular disease, and obesity-related NCDs, whereas high dietary glycemic load has been positively associated with these outcomes (Barclay et al., 2020), (Livesey et al., 2018). Because the present study aims to develop a snack that falls within the medium-GI range for health promotion, this physiological and epidemiological evidence base provides the scientific rationale for targeting a moderate-GI product rather than simply reformulating for macronutrient content alone.

Food loss and waste are global issues that include postharvest losses of fruits and vegetables. Jackfruit, pumpkin, and banana have postharvest losses of 40%-50 % worldwide (Ambuko et al., 2025). In Sri Lanka, jackfruit, pumpkin, and banana are wasted due to poor distribution and networking of surplus production during peak season, inappropriate postharvest handling, and inadequate value addition practices. These commodities have a highly nutritious flour profile, high dietary fiber content, and functional properties that assist commercial food processing by replacing wheat flour with formulated snacks of intermediate- or low-GI value (Adams et al., 2011). Therefore, value addition is highly desired to ensure effective utilization of these crops during the season and off-season, and to support demand-driven cultivation.

Composite flours combining starchy fruit and vegetable sources with wheat flour have previously been explored for GI reduction; for example, banana- and pumpkin-flour composite baked products have been reported to lower predicted GI relative to 100% wheat controls, an effect generally attributed to their resistant starch and non-starch polysaccharide (dietary fiber) content (C. S. Brennan, 2005). Dietary fibre, and soluble fibre in particular, is understood to slow

starch digestion and glucose absorption by increasing digesta viscosity, physically limiting amylase–substrate contact, and delaying gastric emptying (C. S. Brennan, 2005), (Adam et al., 2015). In vitro starch-hydrolysis assays (e.g., the Englyst method) and in vivo clinical GI testing are the two principal approaches used to characterise the glycaemic potential of foods; in vitro hydrolysis indices correlate well with in vivo GI for many starchy foods and are widely used as a practical, lower-cost screening tool during product development, although they remain a predictive rather than a clinically validated measure (Englyst et al., 2003), (Germaine et al., 2008). Despite this body of work, comparatively little research has combined jackfruit, pumpkin, and green banana flours together with a mushroom-based protein filling in a single composite bakery product, and even less has coupled such formulation with an in vitro predicted-GI assessment. This represents the specific research gap addressed by the present study, which is distinct from previous single-flour substitution studies in combining three under-utilized, waste-prone crops with a fungal protein source to simultaneously target sensory acceptability, nutritional density, antioxidant capacity, and a medium predicted-GI outcome.

Sri Lanka is facing a severe foreign exchange crisis for wheat flour, and the rising prevalence of gluten intolerance among some consumers has prompted the bakery industry to develop composite alternative flour formulas. It should be noted that the composite snack developed in this study is not a gluten-free product, since wheat flour remains the majority ingredient in every formulation (Table 1); jackfruit, pumpkin, and green banana flours are themselves gluten-free raw materials, but their partial (15–30%) substitution level does not render the final baked snack gluten-free. Thus, this study was undertaken to characterize and compare the major nutritional composition of three crops in Sri Lanka, namely jackfruit, pumpkin, and banana. Develop a sandwich snack acceptable to consumers and evaluate the nutritional composition and antioxidant potential, and pGI of the snack containing various proportions of the above-mentioned crop flours.

2. Materials and methods

2.1. Flour preparation

The research was conducted at the Fruit and Vegetable Processing Laboratory and Analytical Laboratory of the Food Technology Section, Modern Research and Development Complex, Industrial Technology Institute, Malabe, Sri Lanka. Matured jackfruit (*A. heterophyllum*, maturity stage; 13-17 weeks, bulbs colour; bright yellow) flesh, pumpkin (*C. maxima*, maturity stage; 3-4 weeks, flesh colour; yellow), and matured green bananas (*M. acuminata*, maturity stage; 10-12 weeks, peel colour; totally green) were purchased from the supermarkets in the Malabe (6.904° N, 79.955° E) area and cleaned and sliced (0.5 mm thickness). They were steam-blanching for 1.5 min and cooled by immersion in a cold-water bath. Blanched slices were dipped in 0.1% sodium metabisulphite (SMS) and 0.1% citric acid solutions for 5 min. Blanched slices were then dehydrated in a hot-air oven at 60 °C until the moisture content reached 6%, and ground to flour (0.5mm in size) using a Frisch mill. Flours were subsequently packed in polypropylene (PE) bags and stored at room temperature (25±5 °C) with 60 -70% relative humidity (RH) before snack preparation.

2.2. Development of snack and mushroom filling

Each of the three flours (jackfruit, pumpkin, and green banana) was evaluated independently as a partial wheat-flour substitute, at three inclusion levels per flour (**Table 1**), rather than as a single

simultaneous ternary (three-flour) blend; the ternary combination reported in this study (30% jackfruit-layer + 15% pumpkin-layer + 25% green banana-layer, joined by a mushroom filling) is therefore a multi-layer sandwich assembly of three independently optimized single-flour layers rather than one homogeneous tri-composite flour. This design choice allowed the sensory contribution of each flour to be resolved without confounding between flours, but it does not test whether combining all three flours within one dough layer would perform differently; this is stated as a limitation in Section 4. Jackfruit, pumpkin, and green banana flours were mixed with wheat flour in different proportions, as shown in **Table 1**, to produce a sandwich snack. Sieved wheat flour was mixed with jackfruit, pumpkin, or green banana flours to obtain composite flour mixtures as presented in **Table 1**. Dry ingredients such as salt, margarine, sugar, and activated yeast in lukewarm sugar solution were added. Dough was kneaded and covered with a cling film for 15 min. Each dough was sheeted and baked at 200 °C for 40 min in a pre-heated oven. Each baked sheet was allowed to cool and then cut into pieces.

Table 1: Formulations of Jackfruit, pumpkin, and green banana flour snack layers

Ingredient (g)	Jackfruit flour formula			Pumpkin flour formula			Green banana flour formula		
	1	2	3	4	5	6	7	8	9
Wheat flour (%)	70	75	80	75	80	85	70	75	80
Substitution flour (%)	30	25	20	25	20	15	30	25	20
Margarine	20	20	20	20	20	20	20	20	20
Salt (NaCl)	1	1	1	1	1	1	1	1	1
Refined white sugar	15	15	15	15	15	15	15	15	15
Leavening agent(yeast)	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Egg	25	25	25	25	25	25	25	25	25
Vanilla flavour	2	2	2	2	2	2	2	2	2
Potable water	35	35	35	35	35	35	35	35	35

Mushroom fillings were prepared using the method described by Bhuiyan (Bhuiyan & Rana, 2012). Cleaned oyster mushrooms were blended, and the paste was placed in a vessel with a spice bag containing all spices according to formula 1 in **Table 2**. Then the mixture was heated until the bulk volume was reduced to up to 1/3 of its initial volume. Sugar, salt, and the thickening agent (i.e., cornstarch) were added and mixed while continuously heating. The spice bag was removed, and the remaining parts of salt and sugar were added. Mushroom filling was hot-filled into a pasteurized glass jar. Fresh milk was added to formulas 2 and 3 at the stage when the volume was reduced to 1/3 and allowed to boil for 6 min. The mushroom filling obtained from formula 2, with an additional 1 min of blending and 1 min of cooking, was considered formula 3.

Table 2: Formulations of mushroom fillings

Ingredient (g)	Mushroom filling formulations		
	Formula 1(F1)	Formula 2(F2)	Formula 3(F3)
Oyster mushroom	100	80	80
Fresh milk	0	20	20
Sugar	7.6	7.6	7.6
Salt (NaCl)	0.5	0.5	0.5
Vinegar	5	5	5
Onion	1.2	1.2	1.2

Garlic	0.1	0.1	0.1
Corn starch	0.1	0.1	0.1
Cardamom	0.05	0.05	0.05
Black pepper	0.05	0.05	0.05
Cinnamon	0.05	0.05	0.05
Red chili	0.05	0.05	0.05
Clove	0.05	0.05	0.05
Sodium benzoate	0.07	0.07	0.07
Method of preparation	1/3 volume reduction	1/3 volume reduction 5 min cooking with milk	1/3 volume reduction 5 min cooking with milk 1 min cooking after blending

2.3. Colour measurements of flours

Colour measurements of flour types were determined using a Minolta Chroma Meter (Konica Minolta, CR400, Japan) with CR-A43 calibration, according to the D65 CIE $L^*a^*b^*$ method (Starches, 2007). Where L^* , a^* , and b^* indicate relevant values of flour, and the lightness is indicated by L^* , which ranged from black ($L=0$) to white ($L=100$). Then, a^* and b^* indicate green (-) to red purple (+) and blue (-) to yellow (+), respectively. Each flour sample was levelled into the sample cell without compaction and measured in triplicate at three different points per sample to account for surface heterogeneity, and the mean of the nine readings (three points $\times$ three replicate samples) is reported.

2.4. Proximate composition of flours and snacks

The moisture content was determined by the oven drying method at 105 °C for 5h (Horwitz, 2006). Protein content was determined by the method described in UDK 139, the operating manual of Velp Scientifica, which was adapted from AOAC standards (Horwitz, 2006). The sample was hydrolyzed with Concentrated Sulphuric acid, followed by steam distillation. Liberated ammonia was trapped in Boric acid and titrated with HCL. Crude protein was calculated using the general nitrogen-to-protein conversion factor of 6.25, consistent with AOAC (Horwitz, 2006). A lower, ingredient-specific factor (i.e; 5.7, typically applied to wheat/cereal-gluten protein) was considered but not adopted, because no crop-specific nitrogen-to-protein conversion factors have been validated in the literature for jackfruit, pumpkin, or green-banana flour; applying the general factor of 6.25 is therefore the more conservative and widely comparable choice for this mixed-matrix study, and the resulting values should be interpreted as crude protein (total nitrogen $\times$ 6.25) rather than true protein. Ash content was determined by heating the sample to 550 °C until white ash formed (Harris & Marshall, 2017). Fat content was determined by the method described in the operating manual of the Gerhardt fat extractor (Soxtherm unit) using petroleum ether as solvent (Nielsen, 2010). Crude fiber content was determined by the method described in the operating manual of the Foss Fibertec system, which was adapted from AOAC standards (Nielsen, 2010) by hydrolysis with acid and alkali, followed by ash determination of the residue. Total DF contents of the snack sample were determined by the enzymatic gravimetric method as described by Asp (Asp et al., 1983). In this method, starch and protein are digested using enzymes into small fragments. Ethanol is used to precipitate the soluble fiber, and both soluble and insoluble fiber are recovered by filtration.

2.5. Functional properties of flours and snacks

Phenolic compounds were extracted from flour and ground snack samples in methanol using a method adapted from that described for plant extracts by Singleton et al. (1999), as previously applied to Sri Lankan flour and food matrices by (Arachchige et al., 2020). Approximately 75 g of each flour sample was shaken overnight at room temperature (28 ± 2 °C) using an orbital shaker (150 rpm) with 4 times the sample weight (300 ml) of 99.8% methanol solvent. Extracts were centrifuged by SIGMA Laborzentrifugen (3700 rpm for 15 min), and supernatant was evaporated in a Heidolph rotary evaporator (120 rpm, 40 °C, 200 Mbar). Extracts were stored at 4 °C for further use. Each sample from the evaporated extracts was weighed separately to get the crude extract. Extracts were collected into Eppendorf tubes and labeled. Total Phenolic Content (TPC) and Total Flavonoid Content (TFC) were determined using the Folin-Ciocalteu and aluminium-chloride colorimetric methods, respectively, following the original protocols of Singleton et al. (1999). Ferric Reducing Antioxidant Power (FRAP) of the sample extracts were determined using the methods described by Benzie and Strain (1996). All functional-property assays were performed in triplicate ($n = 3$) per sample.

2.6. Sensory evaluation

Sensory evaluation was conducted for each flour-based snack layer and for the mushroom-filled sandwich snack using a 9-point hedonic/rating scale with ranking method administered by 10 members of panelists and their characteristics (age range, sex distribution, trained vs semi-trained status, and training procedure). Evaluations were conducted under uniform room temperature, lighting type, and humidity during sensory sessions. Samples were assigned random 3-digit codes and randomized presentation order was used to minimize bias, following standard sensory-evaluation practice (Lawless, 1999). The data were statistically analyzed using SPSS 22 (IBM, USA) using the Friedman test, a non-parametric alternative to repeated-measures ANOVA appropriate for ranked sensory data, to obtain mean rank comparisons within each flour-based formulation and mushroom-filling formulation. Pairwise multiple comparisons were performed and the specific post-hoc test which is known as Dunn–Bonferroni pairwise comparison was used for the confirmation.

2.7. Determination of *in vitro* starch digestibility of snack and estimation of predicted glycemic index (pGI)

In vitro starch digestibility of ground snack samples was determined using a method adapted from Englyst et al. (1992), the internationally recognized reference method for classifying nutritionally important starch fractions, with modification. Three replicates for each sample were performed. White bread was used as a reference, and digestion and dialysis were carried out in the same manner. Available carbohydrate content was calculated using the by-difference method (Eq. (1)).

$$\text{Available carbohydrate content} = 100 - (\% \text{ crude protein} + \% \text{ crude fat} + \% \text{ moisture} + \% \text{ ash} + \% \text{ total dietary fiber}). \quad (1)$$

A 2 g sample of the available carbohydrate portion was taken and placed in dialysis bags. Ten milliliters of pooled human saliva was added and stirred for 10 seconds to provide oral (salivary α -amylase) digestion. The volume was adjusted to 35 ml with distilled water. The samples were

dialyzed against 800 mL of distilled water at 37 °C for 3 h. Initial distillate (0.5 ml) and dialysate samples (0.5 ml) at 1 h, 2 h, and 3 h were collected into test tubes in triplicate. Distilled water (0.5 ml) was added to each tube, and total sugar was analyzed by the 3,5-dinitrosalicylic acid method (1 ml of DNS). 50 µl of each test tube portion was plated into micro wells, and each well was diluted with 150 µl distilled water. Finally, absorbance was measured at 540 nm using a 96-well microplate reader (SpectraMax Plus 384, Molecular Devices, USA). Reducing sugar was assayed in solutions using the methods described, with some modifications. A series of D-glucose solutions was prepared at 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 mg/mL. For each concentration, 1 ml of sugar solution was added to 4 ml of DNS reagent. Tubes of different concentrations were placed in a boiling water bath for 5 min and rapidly cooled down to room temperature. Absorbance was measured at 540 nm using a 96-well microplate reader (SpectraMax Plus 384, Molecular Devices, USA). A standard curve for D-glucose (0.1–0.6 mg/mL) was used to convert absorbance to reducing-sugar equivalents. A hydrolysis curve was plotted showing % starch hydrolysis over time. GI calculations were performed according to Germaine et al. (2008): the areas under the hydrolysis curves of the test and reference foods were used to calculate the Hydrolysis Index (HI) (Eq. (2)) and predicted GI (pGI) (Eq. (3)).

$$\text{Hydrolysis index (HI)} = \text{Area under the curve of test food} \times 100 \quad (2)$$

$$\text{Predicted GI value (pGI)} = 39.71 + (0.549 \times \text{HI}) \quad (3)$$

2.8. Statistical Data Analysis for Elemental Flours

The statistical analysis of data was carried out for the proximate composition of flours using the ANOVA technique at the 5% significant level ($p = 0.05$). Normality of residuals and homogeneity of variances were checked prior to ANOVA. Mean comparisons were performed using the Tukey test. For all analyses, MINITAB 17 statistical software was used.

3. Results and discussion

3.1. Flour preparation

Drying and flour preparation are suitable remedies to extend the shelf life and ensure the safe storage of fruits and vegetables, given their perishable nature. Hot-air drying has been used as a simple, common drying method for fruits and vegetables, providing a desired color profile and acceptable nutritional value. Pre-cleaning in potable water and dipping in food-grade chlorinated water were performed as preprocessing steps for surface sterilization. Slice thickness is vital for maintaining even drying and ultimately offers a better color profile. Blanching and citric acid treatment inhibit polyphenol oxidase enzyme activity, which may help prevent browning. Particle size (<0.05 mm) of flour is important for rheological properties, such as hydration capacity, and for improved sensory and textural attributes of the final product.

3.2. Proximate composition of flours

The moisture, crude protein, crude fat, total ash, and crude fiber contents of flour treatments are given in **Table 3** on a dry weight basis.

Table 3: Proximate composition of jackfruit, pumpkin, and banana flour (% w/w in dry weight basis)

Flour type	Moisture	Crude protein	Crude fat	Total ash	Crude fiber
Jackfruit flour	8.74 ± 0.04 ^a	4.86 ± 0.23 ^a	0.15 ± 0.07 ^b	1.95 ± 0.02 ^c	2.72 ± 0.03 ^b
Pumpkin flour	5.08 ± 0.01 ^c	4.45 ± 0.09 ^b	0.75 ± 0.01 ^a	3.03 ± 0.04 ^a	8.75 ± 0.01 ^a
Banana flour	8.32 ± 0.03 ^b	4.43 ± 0.03 ^b	0.24 ± 0.03 ^b	2.81 ± 0.02 ^b	1.16 ± 0.01 ^c
Wheat flour	12.49 ± 0.39	8.28 ± 0.41	1.72 ± 0.16	1.52 ± 0.14	NA

*Values are presented as "Mean ± SD" of three independent determinations. Mean values within a column with different letters are significantly different ($p \leq 0.05$). NA- Not analyzed.

3.2.1. Moisture content

High moisture content affects the shelf life of flour by accelerating mold growth, insect infestation, agglomeration, and moisture-mediated deteriorated reactions (Nasir et al., 2003; Hasmadi, 2021). Therefore, flour specifications usually limit flour moisture to 14% or less. All three flour types had a moisture content less than 10% (Table 3), which offers longer storage stability as commercial dry food products and is lower than that of wheat flour (12.49%).

3.2.2. Crude protein content

Proteins contribute to the psychochemical properties of food, such as its textural attributes and flavor. Crude protein content (total nitrogen $\times$ 6.25) was significantly ($p \leq 0.05$) high in the jackfruit flour (4.85%) compared to pumpkin (4.45%) and green banana (4.43%) flour. A reported study (Kulaitien et al., 2014) showed that pumpkin flour had a higher protein content (8.35–11.33%). It may be due to differences in geographical origin and the vegetation period of cultivar (Kulaitien et al., 2014), (Hajas et al., 2017). The reported date indicated that the protein content on a dry-basis of eight different varieties of green banana flours ranged from 2.5% to 3.3% (da Mota et al., 2000). It may be due to differences in geographical origin, cultivar, and maturation stage of green banana. Research reported that the protein content of wheat flour was 7.17% (Aziah & Komathi, 2009), whereas our results showed 8.28% protein. On average, all three flours tested had lower protein content (4.58%) than wheat flour.

3.2.3. Crude fat content

Lipid compounds act as a source of essential fatty acids and an energy supply. In addition, lipids may cause off-flavors in stored flours, thereby affecting food quality through rancidification. Crude fat content was significantly ($p \leq 0.05$) higher in the pumpkin flour compared to jackfruit and green banana flour (Table 3). Crude fat content of pumpkin flour varies 2.45–3.21% (Kulaitien et al., 2014). Variation of the results was due to differences in the pumpkin cultivar and geographical origin. The crude fat content of green banana flour was 0.5% (Islam et al., 2014), which is similar to the result of the current study. The crude fat content of jackfruit (0.15%), pumpkin (0.75%), and green banana (0.24%) flours was lower than that of wheat flour (1.72%). However, the lower fat content (1.32%) in wheat flour than the results reported by Aziah & Komathi (2009) in this study.

3.2.4. Crude fiber content

Crude fiber content was significantly ($p \leq 0.05$) different in the analyzed flour samples. Crude

fiber contents of jackfruit, pumpkin, and green banana flours were reported in the literature as 2.72%, 8.75%, and 1.16%, respectively. The crude fiber content of pumpkin flour varies from 5.61% to 6.66% (Kulaitien et al., 2014), which was slightly lower than the results of the current study. A higher crude fiber content (4.2%) in green banana flour was reported, which may be due to variation in the banana cultivar's maturation stage. Compared with wheat flour, which contains 0.03% (Aziah & Komathi, 2009) of crude fiber, these three fruit flours contained a substantial amount of fibrous material. The amount of crude fiber in the pumpkin flour was significantly ($p \leq 0.05$) higher than the other two flour types. That can be considered a suitable material to incorporate into the development of value-added food products with a high fiber content.

3.2.5. *Total ash content*

Total ash content was significantly different ($p \leq 0.05$) among the tested flour samples (**Table 3**). The ash content of jackfruit (1.95%), pumpkin (3.03%), and green banana (2.81%) flours was higher than that of wheat flour (1.52%) (Table 3). These three flour types, as food ingredients with high ash content, can contribute significantly to the value addition of foods. According to reported data, ash content of pumpkin flour varies from 6.81% to 8.89% (Kulaitien et al., 2014). Ash content of banana flour was 1.2% (Islam et al., 2014). This result is lower than the result reported in the present study. Genetic variation, botanical origin, soil, environmental conditions, and nutrient interactions were reported as possible reasons for differences in flour ash content (Kulaitien et al., 2014).

3.2.6. *Analysis of functional properties of flour*

The distribution and composition of phenolic phytochemicals are affected by maturity, cultivars, horticultural practices, geographic origin, growing season, postharvest storage conditions, and processing procedures (Kim et al., 2003). Antioxidant activities of pumpkin flour and green banana flour have been reported by several researchers; however, there is limited information on the drying method, extraction procedure, and antioxidant potential of jackfruit flesh flour.

3.2.7. *Extraction of flours*

Extraction and purification of antioxidants from natural sources are vital aspects in functional foods, food additives, and the nutraceutical industry, as they liberate phenolic compounds through rupturing plant tissues or diffusion. The rotary evaporator operates under reduced pressure, minimizing the effect of temperature on phenolic compounds. Here, flours of underutilized crops were extracted with 99.8% methanol.

3.3. *Colour measurements of flours*

Jackfruit flour indicates a high L^* value for lightness and a relatively low value for a^* and b^* compared to pumpkin (**Table 4**). A high value of pumpkin flour (**Fig 1A**) indicates the natural presence of carotenoid compounds, which imply yellow, red, and orange colors. Another research on hot-air-dried pumpkin flour (*Cucurbita moschata* Duch) (Que et al., 2008) indicated higher L^* , a^* , and b^* values than the values observed in the present study. The color characteristics of banana flour (L^* , a^* , and b^*) change during ripening, related to enzymatic reactions. Green banana flour indicates high lightness (L^*), high greenness with low (a^*) value, and low yellowness (b^*). The present study's results are supported by the reported data from

Campuzano et al. (2018).



Fig. 1: Elemental flours from (A) Pumpkin, (B) Jackfruit and (C) Green banana

Flour	Colour		
	L*	a*	b*
Pumpkin flour	50.04 ± 1.59 ^a	6.12 ± 0.22 ^a	21.13 ± 0.63 ^a
Jackfruit flour	70.94 ± 2.63 ^b	5.00 ± 0.17 ^b	8.34 ± 0.51 ^b
Green banana flour	59.44 ± 2.50 ^c	6.64 ± 0.29 ^c	5.44 ± 0.29 ^c

Table 4: Colour measurements of elemental flours

*Values are presented as Mean ± SD of three independent determinations (three measurement points per sample). CIE L*a*b*, D65 illuminant. Mean values within a column with different letters are significantly different ($p \leq 0.05$)

3.4. Functional properties of flours

3.4.1. Total polyphenolic and flavonoid contents of flours

The Folin-Ciocalteu method, which measures the reductive capacity of an antioxidant, has been widely used in clinical and nutritional studies of plant-derived foods and biological samples (Lamuela, 2018). Folin–Ciocalteu phenol reagent consists of a mixture of phosphomolybdic and phosphotungstic acids, which turn blue coloured when the reaction occurs (Katarzyna et al., 2017). The procedure is based on comparing the absorbance with a gallic acid standard curve. Total phenolic content is expressed as mg of gallic acid equivalent (GAE) per gram of sample on a dry basis. TPC of methanolic extracts of jackfruit, pumpkin, and green banana flours is given in **Table 5**. According to the results, banana flour has the highest phenolic content of the flours. Jackfruit flour exhibits 0.091 ± 0.008 mg GAE/g phenolic content. Pumpkin flour exhibits 0.73 ± 0.09 mg GAE/g phenolic content. The total phenolic content of pumpkin flour (*Cucurbita moschata* Duch.) reported in the literature was 1.64 mg/g (Que et al., 2008), which was higher than that of freeze-dried pumpkin flour, indicating an increase in phenolic content after hot-air drying. The cultivar variation may lead to differences in phenolic content. The total phenolic content in green banana flour is 0.81 ± 0.05 mg GAE/g. Total polyphenol content in Banana flour (*Musa Acuminata*) was 50.65 ± 0.80 mg GAE/100 g on a dry weight basis (Menezes et al., 2011). Flavonoids are the major phenolic compounds that are the major contributors to the antioxidant capacity of plant material. Flavonoids in fruits and vegetables are consumed as part of the human daily diet. Plants rich in flavonoids can be used to prepare functional foods. TFC of methanolic extracts of jackfruit, pumpkin, and banana flour are given in **Table 5**.

There is limited information on the total flavonoid content of jackfruit and pumpkin flours. Jackfruit flour and pumpkin flour exhibit 0.12 ± 0.01 mg QE/g and 1.77 ± 0.12 mg QE/g, respectively, on a dry weight basis. Green banana

flour exhibits 0.12 ± 0.01 mg QE/g total flavonoid content on a dry weight basis. Flavonoid contents of dessert and plantain banana were ranged from 37.64 ± 0.28 to 84.42 ± 1.63 mg QE/100 g dry weight basis, respectively (Kumar et al., 2019). The variation in flavonoid content observed in the present study may be due to climate conditions, geographic area, variety, and maturity stage. The Folin-Ciocalteu assay used to determine TPC is not highly specific, as nonphenolic compounds contribute to the results. The TFC assay appears to be more specific; however, it shows different specificity for various flavonoids and is subject to interference from phenolic acids with catecholic (o-dihydroxylated) moieties (Katarzyna et al., 2017).

3.4.2. Antioxidant potential using Ferric Reducing Antioxidant Power (FRAP) Assay of flours

The reductive antioxidant reduces ferric ion to ferrous ion by reacting with 2,3,5-triphenyl-1,3,4-triaza-2- azoniacyclopenta-1,4-diene chloride (TPTZ) to form a colored complex at 600 nm with 2,4,6-tripyridyl-s-triazine in acetate buffer (pH 3.6). Ascorbic acid, α -tocopherol, bilirubin, uric acid, and polyphenolic compounds such as catechins and other flavonoids in plant-based foods react in the FRAP. These measures total the sample's reductive antioxidant capacity (Benzie, 2014). FRAP of methanolic extracts of jackfruit, pumpkin, and green banana flours is given in **Table 5**. Jack fruit flour exhibits 0.025 ± 0.005 mg TE/g of ferric reducing antioxidant power. Pumpkin flour exhibits 0.57 ± 0.001 mg TE/g flavonoid content. Hot-air-dried pumpkin flour (*Cucurbita moschata* Duch.) had 13 μ mol Trolox/g for free phenolics and 13 μ mol Trolox/g for bound phenolics. Results from this method cannot be compared with those of the present study due to differences in extraction methods and the units used to express the results. Hot-air-dried pumpkin flours reported slightly higher antioxidant activity than freeze-dried pumpkin flours (Aydin & Gocmen, 2014). FRAP of hot-air-dried pumpkin (*Cucurbita moschata* L.) flour was 482.19 ± 8.48 mg Fe (II)/ 100 g dry basis (Promsakha et al., 2017). This cannot be compared with the results of the present study due to the differences in variety, method, and the units used to express results. Green banana flour exhibits 0.32 ± 0.07 mg TE/g of FRAP. FRAP in banana flour (*Musa acuminata*) was 6.56 ± 0.03 mmol Fe (II)/ 100g dry basis (Menezes et al., 2011). The antioxidant activity of green banana flour (*Musa acuminata*), by the FRAP method, was 358.67 ± 0.01 μ mol of trolox equivalent/100 g dry weight (Menezes et al., 2011). However, cannot be compared with the results of the present study due to differences in variety, method, and the units used to express results. The reaction is nonspecific, and any compound with a suitable redox potential can drive FeIII-TPTZ reduction, which is considered a major limitation in FRAP (Amorati & Valgimigli, 2015).

	Flour		
	Jackfruit flour	Pumpkin flour	Green banana flour
TPC (mg GAE/g)	0.09 ± 0.01^a	0.73 ± 0.09^a	0.81 ± 0.05^a
TFC (mg QE/g)	0.12 ± 0.01^b	1.77 ± 0.12^b	0.12 ± 0.01^b
FRAP (mg TE/g)	0.025 ± 0.02^c	0.57 ± 0.01^c	0.32 ± 0.07^c

Table 5: TPC, TFC and FRAPs of hot airdried jackfruit, pumpkin, and green banana Flour (dry basis)

*Values are presented as "Mean $\pm$ SD" of three independent determinations. Mean values within a column with different letters are significantly different ($p \leq 0.05$)

3.5. Sensory evaluation of snack layers and mushroom fillings

For the jackfruit-flour-based layer, the 30% formulation achieved the highest mean sensory ranks across all attributes (**Fig. 2A**: overall acceptability 2.56, texture 2.50, appearance 2.50, colour

2.56, taste 2.38, odour 2.25; $p > 0.05$), indicating no clear single strongest attribute but consistently higher acceptance than the 25% and 20% formulations. The pumpkin-flour-based layer achieved peak sensory acceptance at the 15% inclusion level (**Fig. 2B**: overall acceptability 2.57, appearance 2.88, colour 2.75, texture 2.75, taste 2.75; $p \leq 0.05$), significantly outperforming the 25% and 30% alternatives in appearance, colour, texture, and taste. The green-banana-flour-based layer received the highest preference at 25% (**Fig. 2C**: overall acceptability 2.60, texture 2.90, taste 2.65; $p \leq 0.05$), dominating overall acceptability and texture, despite a marginal, non-significant drop in odour score relative to the 30% variant (2.0 vs 2.1). Among the mushroom-filling variations, Formulation F1 (**Fig. 2D**: sum of ranks 14.5–16.6 across attributes) received the highest sensory ranking, ahead of F2 (10.4–13.1) and F3 (8.9–12.2), consistent with superior taste and texture performance. Consequently, to maximize overall consumer acceptability and sensory quality, the optimal composite snack integrated the 30% jackfruit-flour layer, the 15% pumpkin-flour layer, and the 25% green-banana-flour layer, bound together by the F1 mushroom filling. This optimal combination was derived by selecting the best-performing inclusion level from each flour's independent sensory optimization series, rather than by directly comparing the assembled three-component sandwich against alternative three-component formulations in a single sensory test.

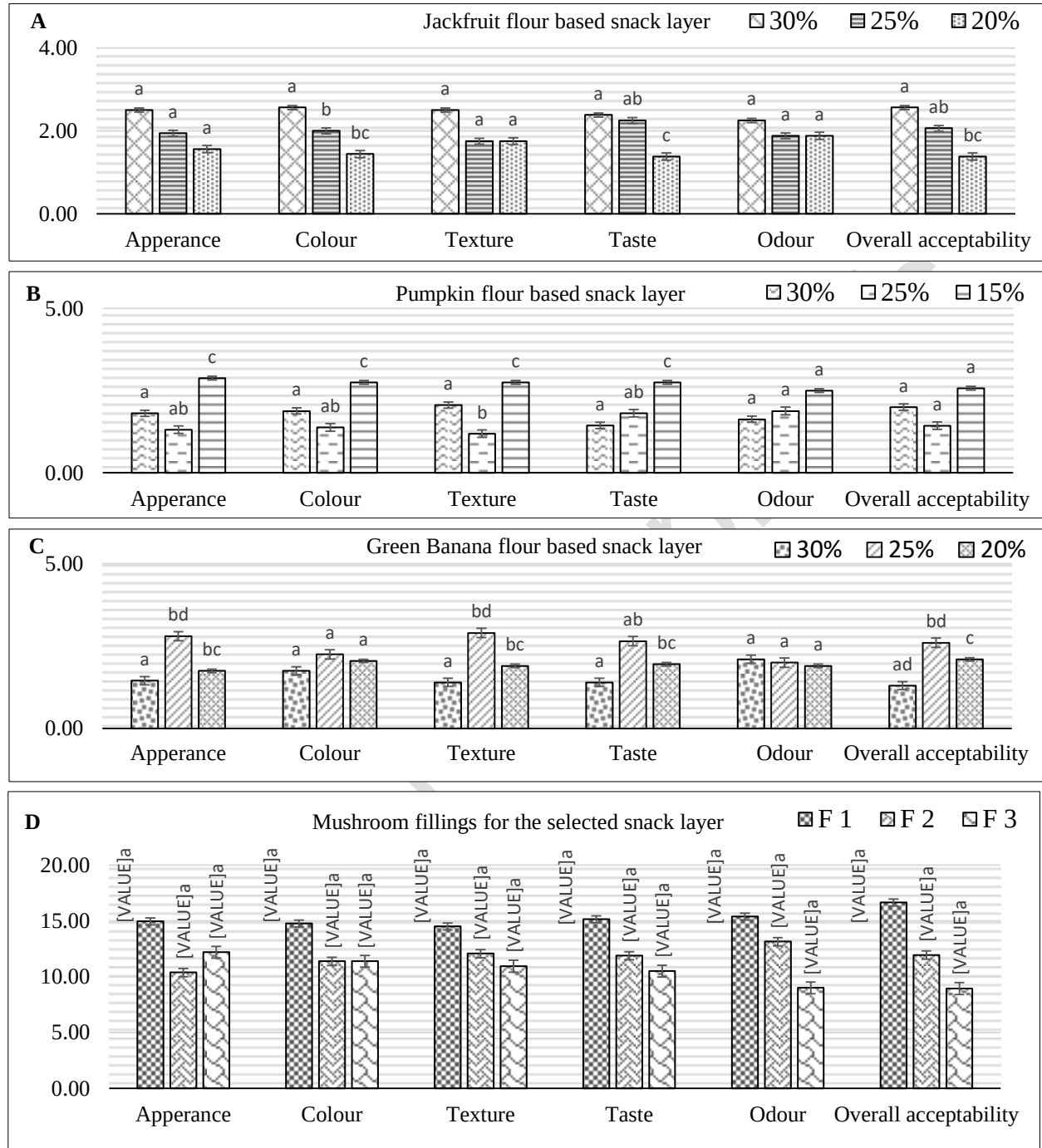


Fig. 2: Sensory analysis of snack layers made with different flours from (A) Jackfruit, (B) Pumpkin, and (C) Green banana, and (D) mushroom fillings; Data are presented as mean rank values. Bars sharing the same lowercase letter within a specific sensory parameter are not significantly different ($p > 0.05$)

3.6. Proximate composition of the snack

Nutritional value of the snack on a dry basis is shown in Table 6. The crude protein content of the snack is determined by the combined Formulation of jackfruit, pumpkin, banana, wheat flour,

and oyster mushroom. Incorporation of mushrooms is a cost-effective way to increase protein and nutritional properties of foods. Formation of an amylose-lipid complex, which has been related to a decrease in lipid content and an increase in the indigestible fraction of starch, may affect the fat content of snacks. It is a desirable trend that people are becoming more health-conscious and omitting snacks high in fat. The dietary fiber content of the snack is governed by the collective Formulation of jackfruit, pumpkin, banana flour and mushroom. It is a valuable feature in the functional food industry that soluble dietary fiber dissolves in the gut and forms a viscous gel, which lowers the absorption of the released glucose. Wheat flour is the main contributor to the total carbohydrate content in developed snacks.

	Moisture content	Crude protein	Crude fat	Total ash	Dietary fibre	Carbohydrate	Caloric value (kcal/100 g)
Snack	30.77 ± 0.03	10.31 ± 0.16	6.18 ± 0.01	2.75 ± 0.01	8.16 ± 0.01	42.82 ± 0.29	264.14 ± 0.16

Table 6: Proximate composition of the selected snack (% w/w in dry weight basis)

* Values are presented as "Mean ± SD" of three independent determinations, dry-weight basis.

3.7. Functional properties of snack

The antioxidant activity of the developed snack reflects the combined contribution of jackfruit, pumpkin, and green banana flour and mushroom filling; because statistical comparisons among final snack formulations were not performed (only a single optimal formulation was analyzed for functional properties, Table 7), the influence of the individual ingredients cannot be statistically partitioned in the present dataset, and the descriptive comparison below should be read as illustrative rather than statistically confirmed. The antioxidant potential of the developed snack is shown in **Table 7**.

Table 7: Functional properties of novel snack

	Functional property (dry weight basis)
TPC (mg GAE/g)	0.31 ± 0.04
TFC (mg QE/g)	0.112 ± 0.008
FRAP (mg TE/g)	0.06 ± 0.01
DPPH radical scavenging activity (IC50 µg/ml)	318 ± 102

*Values are presented as Mean ± SD of three independent determinations, dry-weight basis. IC50 = half-maximal DPPH radical-scavenging inhibitory concentration (lower value = higher radical-scavenging activity).

The antioxidant activity of the novel snack is significantly affected by the addition of jackfruit, pumpkin, banana flour, and mushrooms. An increase in the quantity of vegetable flour led to an increase in the antioxidant activity of bakery products (Wahyono, A., 2020).

3.8. In vitro starch digestibility and predicted glycemic index(pGI)

Snacks usually fall into the high-GI food category, depending on their ingredient composition, including the high-starch content contributed by wheat flour. However, dietary fiber-rich snacks fall into the intermediate GI category (56-69) or the low GI category (≤ 55) due to the reduced amount of digestible carbohydrate present in the formulated snacks. The starch hydrolysis curve is shown in **Fig. 3A**. The predicted GI value for the snack sample, calculated using Eqs. (2) and (3) is shown in **Table 8**.

According to the present study, the jackfruit, pumpkin, green banana flour, and mushroom incorporated snack had a predicted GI of 68.11, falling into the intermediate predicted-GI category. Glycemic response is influenced by the amount of available carbohydrate, protein, amylose, and dietary fibre content, and by starch digestibility; higher dietary fiber and protein content and lower available carbohydrate content of snacks are associated with an intermediate-GI outcome, a property of relevance to non-communicable-disease risk reduction and as a potential dietary aid. Dietary fibre is understood to slow starch digestion by increasing digesta viscosity and limiting amylase access to starch granules; protein and lipids can further reduce the rate of gastric emptying and glucose absorption; and a higher proportion of amylose (relative to amylase-susceptible amylopectin) forms more resistant, compact starch granules that are hydrolyzed more slowly by digestive enzymes (Brennan et al., 2012; Adams et al., 2011). These combined mechanisms plausibly explain why the fiber and protein-enriched composite snack developed here achieved a lower predicted GI than would be expected for a comparable all-wheat-flour product, although this comparison was not directly tested against an all-wheat control in the present study and is noted as a limitation.

Product	Snack
Area under the curve (AUC)	0.5174
HI (%)	51.74
Predicted GI (pGI)	68.11

Table 8: Predicted GI value for snack sample

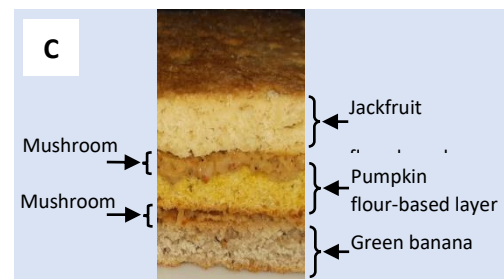
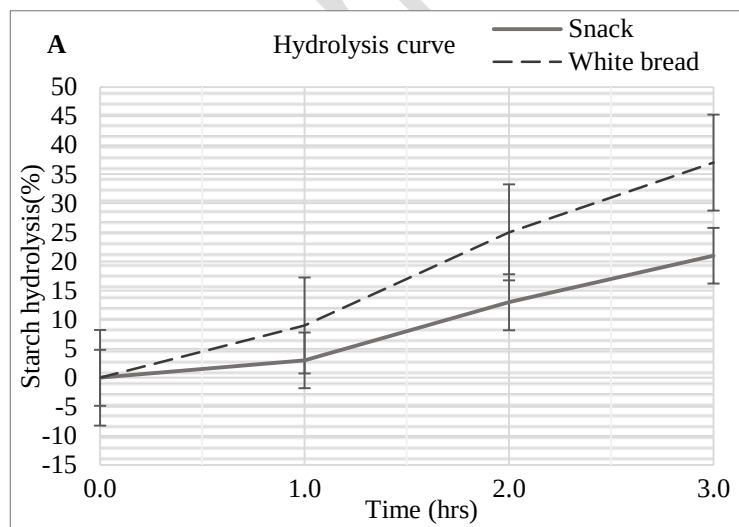


Fig. 3: Starch hydrolysis curve (A) for the snack, (B) Developed sandwich snack and, (C) a cross section

4. Conclusion

This study demonstrates that jackfruit, pumpkin, and green banana flours can be used as partial wheat-flour substitutes (15–30% inclusion) to develop a mushroom-filled composite sandwich snack with a favourable nutritional profile: 10.31% crude protein, 8.16% dietary fibre, and a predicted glycemic index of 68.11, placing it within the intermediate-pGI category. The snack additionally showed measurable antioxidant activity (TPC, TFC, FRAP, DPPH IC₅₀). These findings support the use of jackfruit, pumpkin, and banana flours as a means of increasing the commercial utilization of these crops and reducing postharvest losses in Sri Lanka. Several limitations should be noted when interpreting these results: (i) the predicted GI was derived from a simplified in vitro salivary-amylase hydrolysis assay rather than the full Englyst intestinal-digestion protocol, and has not been validated against in vivo/clinical GI measurement (Section 2.7); (ii) the developed snack is not a gluten-free product, as wheat flour remains its majority ingredient; (iii) the ternary flour combination used in the final product was derived from separate single-flour sensory optimizations rather than a direct sensory comparison of alternative three-component formulations; and (iv) as the funding period for this project has concluded, several methodological details requested during peer review (e.g., raw-material cultivar and storage records, full sensory-panel demographics) could not be retrospectively regenerated and are flagged for author confirmation from original study records rather than reported as new data. Future work should address these limitations through in vivo GI validation, direct three-component sensory comparison, and reporting of full ingredient provenance.

Declarations

Conflict of interest: The authors declare no conflict of interest.

Data availability: Data will be available upon request.

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