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Physicochemical, sensory and storage stability evaluation of tarap (*Artocarpus odoratissimus*)-based breakfast cereal produced by drum drying

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Abstract

Aim: This study aimed to develop a tarap (*Artocarpus odoratissimus*)-based breakfast cereal using brewer's rice as the cereal base and to evaluate the effects of tarap incorporation on its physicochemical properties, sensory acceptability, and storage stability after drum drying.

Methods: Five cereal formulations containing 0%, 5%, 10%, 15%, and 20% tarap pulp were prepared and processed using a twin-drum dryer. The resulting products were analysed for proximate composition, water absorption capacity, colour characteristics, and total dietary fibre. Sensory evaluation was carried out using a 9-point hedonic scale. The most acceptable formulation was further evaluated through a 28-day storage study under ambient conditions, during which moisture content, water activity (a_w), and colour stability (ΔE^*ab) were monitored.

Results: Tarap incorporation significantly affected several quality attributes of the cereal. Moisture content decreased from 9.61% in the control to 0.89% in formulation D, while ash and protein contents were higher in tarap-containing formulations. Total carbohydrate content ranged from 82.11% to 89.77%. Water absorption capacity ranged from 182.22% to 213.33%, with no significant difference among formulations. Increasing tarap levels also produced darker, redder, and more yellowish cereal flakes. Sensory evaluation showed that formulation D (20% tarap) achieved the highest scores for colour, taste, texture, and overall acceptability, with an overall score of 7.32 ± 1.24. During storage, both the control and formulation D maintained low a_w values (0.18–0.23), while formulation D showed lower moisture content and better colour stability at the end of storage.

Conclusions: Tarap can be incorporated into drum-dried breakfast cereal to produce a sensory acceptable product with promising short-term physical stability under ambient conditions. However, microbiological safety, together with longer-term storage stability, must be verified before the product can be considered suitable for future food application or commercialization.

Keywords

tarap, *Artocarpus odoratissimus*, drum drying, brewer's rice, breakfast cereal, physicochemical properties, storage stability

Introduction

Breakfast cereals are widely consumed as convenient and nutritionally balanced breakfast foods. Numerous studies have reported that cereals, particularly those derived from whole grains, provide important nutritional benefits due to their high content of carbohydrates, protein, iron, and calcium [1]. Regular consumption of breakfast cereals has also been associated with improved dietary quality and increased intake of essential nutrients and recommended food groups [2]. In recent years, the development of fruit-based cereals has attracted increasing attention as the incorporation of fruits can enhance the nutritional value of cereal products by providing additional dietary fiber, vitamins, minerals, and bioactive compounds such as carotenoids and polyphenols [3, 4]. Despite this growing interest, many commercially available breakfast cereals still contain high levels of refined sugars and artificial additives. This has created increasing demand for healthier cereal products formulated with natural ingredients and functional components.

Tarap (*Artocarpus odoratissimus*) is a tropical fruit widely cultivated in Sabah, Sarawak, and parts of the Philippines and Indonesia. The fruit is characterized by its soft, sweet, and aromatic pulp and is known to contain substantial amounts of carbohydrates, dietary fiber, and essential minerals such as potassium, iron, and zinc, as well as various vitamins and bioactive compounds [5]. Previous studies have reported that tarap exhibits several functional properties including antibacterial, anticancer, and antidiabetic activities [6]. Furthermore, different parts of the fruit including the peel, seeds, and pulp contain antioxidant compounds such as polyphenols and flavonoids that contribute to free radical scavenging activity [7]. Despite its promising nutritional and functional properties, the commercial utilization of tarap remains limited. The fruit is highly perishable due to its high moisture content and short postharvest shelf life, which restricts its storage, transportation, and market distribution. According to the Department of Agriculture Malaysia, although Sabah remains the main production region with an annual production of approximately 1,920.39 metric tons, tarap production has declined by more than 67% between 2019 and 2023. This decline highlights the underutilization of the fruit and the need for value-added processing approaches that can extend its shelf life while enhancing its economic value.

In addition to the underutilization of tarap, agro-industrial by-products such as brewer's rice also remain largely undervalued. Brewer's rice is a by-product of rice milling consisting mainly of small broken rice fragments, often accompanied by portions of bran and germ [8]. Although brewer's rice possesses a nutritional profile comparable to white rice, with additional dietary fiber and micronutrients contributed by bran and germ fractions, it is frequently utilized in low-value applications such as animal feed due to its susceptibility to lipid oxidation and limited shelf stability [9]. The valorization of brewer's rice into human food products aligns with the principles of sustainable food systems and circular economy, where agricultural by-products are converted into value-added food ingredients with improved nutritional and economic value.

To effectively incorporate both tarap pulp and brewer's rice into cereal formulations, an appropriate processing technique is required. Drum drying is widely used in the food industry for producing cereal flakes and instant cereal products due to its ability to process viscous or slurry-based materials such as fruit pulps and cereal pastes [10]. The technique involves spreading the slurry as a thin film on a heated rotating drum, allowing rapid moisture removal and formation of dried flakes. Compared with other drying methods such as spray drying or freeze drying, drum drying is particularly suitable for thick and fibrous materials and can produce shelf-stable products with relatively low processing costs while maintaining acceptable nutritional quality [11, 12]. Therefore, the application of drum drying provides a promising approach for transforming highly perishable fruit pulp into stable cereal products.

This study was carried out to develop a tarap-based breakfast cereal using brewer's rice as the main base and drum drying as the processing method. The developed formulations were then assessed in terms of proximate composition, physicochemical properties, sensory acceptability, and storage stability under ambient conditions.

Materials and methods

Raw materials

Brewer's rice was obtained from a local rice mill in Sabah, Malaysia (Sazarice Sdn. Bhd.). Ripe tarap fruits were purchased from the Kundasang local market in Ranau, Sabah. Tarap fruits were selected based on appropriate ripeness and the absence of visible physical defects. Upon arrival at the laboratory, the fruits were washed thoroughly with distilled water, and the edible pulp was manually separated. The pulp was then blended with water to obtain a uniform slurry for cereal formulation.

Sample preparation of tarap-based cereal

Five cereal formulations were prepared by varying the proportion of tarap pulp and brewer's rice while maintaining a constant water content, as shown in Table 1. The cereal formulation was adapted from Okoye et al. [13], with modifications to the proportions of tarap pulp and brewer's rice in order to produce five formulations containing 0%, 5%, 10%, 15%, and 20% tarap pulp.

Table 1. Formulation of tarap-based cereal prepared with different levels of tarap pulp and brewer's rice.

Ingredient	Formulations (%)				
	Control	A	B	C	D
Brewers' rice	80	75	70	65	60
Tarap	0	5	10	15	20
Water	20	20	20	20	20

The required amounts of brewer's rice and tarap pulp were weighed according to the formulation and blended with water to produce a homogeneous slurry. The slurry was then subjected to drum drying to produce thin cereal flakes.

All formulations were processed using a twin-drum dryer (Model AM-2530/10, Agridon Sdn. Bhd., Malaysia) at a fixed drum speed of 3 rpm as conducted by Yang et. al. [14]. The slurry was manually fed and spread onto the drum surface under the same operating setup for all formulations. The dried sheet was removed using a stainless-steel scraper, cooled to room temperature, and ground into powder. Although the dryer operated under stable boiler and preset equipment conditions, specific parameters such as drum surface temperature, steam pressure, drum gap, feed rate, and feed total solids were not recorded during the experimental runs. To ensure consistency, all samples were processed using the same drum dryer, drum speed, feeding approach, and scraping conditions.

Proximate composition

Proximate composition analysis of the cereal samples was carried out to determine moisture content, ash, protein, and fat contents using standard methods of the Association of Official Analytical Chemists (AOAC) [15]. All analyses were performed in triplicate. Moisture content was determined by oven drying the samples at 105°C to constant weight was achieved, while ash content was measured by incineration in a muffle furnace at 550°C. Protein content was determined using the Kjeldahl method, and crude fat was analysed using Soxhlet extraction. Total carbohydrate content was calculated by the difference, where the combined percentages of moisture, ash, protein, and fat were subtracted from 100 [16, 17]. Total dietary fibre was determined using the AOAC enzymatic–gravimetric method (AOAC 985.29) with a commercial assay kit (K-TDFR-200A, Megazyme).

Physicochemical analysis

Water absorption capacity

Water absorption capacity of the tarap-based cereal was measured to assess its hydration behaviour. A 5 g sample was mixed with 50 mL of distilled water, stirred thoroughly, and left to stand at room temperature (25 ± 2°C) for 30 min. The hydrated cereal was then separated from the excess water using a strainer, and its final weight was recorded. Water absorption capacity was expressed as the percentage increase in sample weight following water absorption.

Colour analysis

Colour analysis of the tarap-based cereal samples was carried out using a colorimeter (CR-400, Konica Minolta, Japan). The instrument was calibrated prior to use, and the colour of each sample was recorded using the CIELAB system in terms of L*, a*, and b* values. The triplicate readings were taken as the final result for each formulation.

Sensory evaluation

Sensory evaluation was conducted using 75 untrained panelists to assess consumer acceptability of the developed cereal products by Ling et al. [18]. An affective test using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) was employed to evaluate colour, taste, texture, and overall acceptability.

The cereal samples were coded with random three-digit numbers and presented to the panelists in random order. Panelists were asked to evaluate each sample and record their preference scores based on the specified attributes. Drinking water was provided to cleanse the palate between sample evaluations. The sensory evaluation protocol involving human participants was conducted in accordance with the Declaration of Helsinki and was reviewed and approved by the Medical Research Ethics Committee, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah (Approval code: JKEtika 5/25 (68)). Participation was voluntary and informed consent was obtained from all panelists prior to the evaluation. The formulation with the highest overall acceptability score and favourable sensory performance across the evaluated attributes was selected for further storage study.

Shelf-life study

The storage stability of the cereal was evaluated through a 28-day real-time shelf-life study under ambient conditions. The control and selected formulation were packed in aluminium pouches and stored at 25 ± 2°C. Analyses were performed on days 0, 7, 14, 21, and 28 to monitor changes in moisture content, water activity (a_w), and colour. Measurements were performed in triplicate unless otherwise stated, and results were expressed as mean ± standard deviation where applicable. Moisture content was measured by oven drying, and a_w was determined using a water activity meter. For colour stability, L*, a*, and b* values were measured in triplicate, and the mean values were used to calculate the total colour difference, ΔE*ab, at each storage interval. The overall colour change during storage was expressed as total colour stability (ΔE*ab) as presented in Equation (1).

$$\Delta E^{*}ab = \sqrt{\left[\left(\Delta L^{*} \right)^{2} + \left(\Delta a^{*} \right)^{2} + \left(\Delta b^{*} \right)^{2} \right]} \quad (1)$$

where ΔL^*, Δa^*, and Δb^* represent the differences between colour coordinates on 0, 7, 14, 21 and 28 days. The ΔE^*ab metric is based on the CIE76 colour difference model.

Statistical analysis

All experiments were performed in triplicate unless otherwise stated, and the results are presented as mean ± standard deviation. Data were analysed using one-way analysis of variance (ANOVA) to determine significant differences among formulations for proximate composition, physicochemical properties, and sensory attributes. Where significant differences were detected, mean comparisons were performed using Tukey's honestly significant difference (HSD) test at a significance level of $p < 0.05$. For total dietary fibre, comparisons between the control and the selected formulation were analysed using an independent samples t-test at $p < 0.05$. Data from the storage study were analysed descriptively and, where applicable, by comparing changes across storage time and between samples. Statistical analysis was performed using IBM SPSS software.

Results

Proximate composition

The proximate composition of all five cereal formulations (control, A, B, C, and D), containing 0%, 5%, 10%, 15%, and 20% tarap pulp, respectively, is presented in Table 2. Compared with the control group, each formulation shows significant differences in moisture, protein, and total carbohydrate content. The moisture content of the cereal samples ranged from 0.89% to 9.61%. The control sample exhibited the highest moisture content (9.61 ± 0.12%), while formulation D showed the lowest moisture content (0.89 ± 0.17%).

Table 2. Proximate composition (%) of drum-dried tarap-based breakfast cereal formulations.

Formulation	Moisture content (%)	Ash content (%)	Protein content (%)	Fat content (%)	Total carbohydrate content (%)
Control	9.61 ± 0.12^{d}	0.18 ± 0.03^{a}	7.75 ± 0.15^{a}	0.35 ± 0.06^{ab}	82.11^{a}
A	2.19 ± 0.10^{c}	0.63 ± 0.25^{b}	8.43 ± 0.13^{b}	0.49 ± 0.13^{b}	88.26^{b}
B	2.35 ± 0.13^{b}	0.56 ± 0.05^{ab}	8.31 ± 0.18^{b}	0.23 ± 0.05^{ab}	88.55^{b}
C	1.42 ± 0.08^{b}	0.57 ± 0.24^{ab}	8.62 ± 0.09^{b}	0.16 ± 0.08^{a}	89.23^{b}
D	0.89 ± 0.17^{a}	0.65 ± 0.04^{b}	8.44 ± 0.06^{b}	0.25 ± 0.19^{ab}	89.77^{b}

Values are presented as mean ± standard deviation (n = 3). Different lowercase letters within the same column indicate significant differences among formulations ($p < 0.05$). A: 5% tarap; B: 10% tarap; C: 15% tarap; D: 20% tarap.

Ash content varied between 0.18% and 0.65%, with the control formulation having the lowest ash value (0.18 ± 0.03%) and formulation D showing the highest value (0.65 ± 0.04%). Protein content ranged from 7.75% to 8.62%. Although formulations containing tarap pulp showed slightly higher ash and protein values than the control, the magnitude of the differences was small.

Fat content of the cereal formulations ranged from 0.16% to 0.49%. Formulation A recorded the highest fat content (0.49 ± 0.13%), while formulation C showed the lowest value (0.16 ± 0.08%). Total carbohydrate content ranged from 82.11% to 89.77%. The highest carbohydrate content was observed in formulation D (89.77%), whereas the control formulation recorded the lowest value (82.11%).

Physicochemical properties

The physicochemical properties of all five cereal formulations, including water absorption capacity and colour parameters, are presented in Table 3.

Water absorption capacity

Table 3 shows that the water absorption capacity ranged from 182.22% to 213.33%. Formulation B exhibited the highest water absorption capacity value (213.33 ± 13.33%), whereas formulation C showed

Table 3. Physicochemical properties of drum-dried tarap-based breakfast cereal formulations.

Formulation	Water absorption capacity (%)	Colour analysis		
		L*	a*	b*
Control	197.78 ± 23.41[a]	83.71 ± 1.25[c]	0.64 ± 0.11[a]	7.70 ± 0.56[a]
A	200.00 ± 11.55[a]	82.55 ± 0.71[b]	0.65 ± 0.02[a]	16.43 ± 0.31[b]
B	213.33 ± 13.33[a]	75.05 ± 1.50[b]	2.46 ± 0.04[b]	21.89 ± 0.12[c]
C	182.22 ± 3.85[a]	74.06 ± 0.48[a]	4.24 ± 0.47[c]	25.82 ± 1.15[d]
D	193.33 ± 13.33[a]	69.55 ± 1.04[a]	6.65 ± 0.46[d]	27.84 ± 0.21[d]

Values are presented as mean ± standard deviation ($n = 3$). Different lowercase letters within the same column indicate significant differences among formulations ($p < 0.05$). A: 5% tarap; B: 10% tarap; C: 15% tarap; D: 20% tarap.

the lowest value (182.22 ± 3.85%). However, no significant differences ($p > 0.05$) were observed among the formulations for water absorption capacity.

Colour characteristics

The colour parameters (L*, a*, and b*) of the cereal samples are presented in Table 3. In contrast to water absorption capacity, significant differences ($p < 0.05$) were observed for most formulations for all colour attributes. The lightness (L*) values ranged from 69.55 to 83.71, with the control sample showing the highest L* value (83.71 ± 1.25). Lower L* values were observed in samples with higher tarap incorporation. The redness (a*) values ranged from 0.64 to 6.65, with formulation D recording the highest value (6.65 ± 0.46). The yellowness (b*) values ranged from 7.70 to 27.84, with formulation D exhibiting the highest b* value (27.84 ± 0.21). Figure 1 shows the visual colour differences among the cereal formulations.

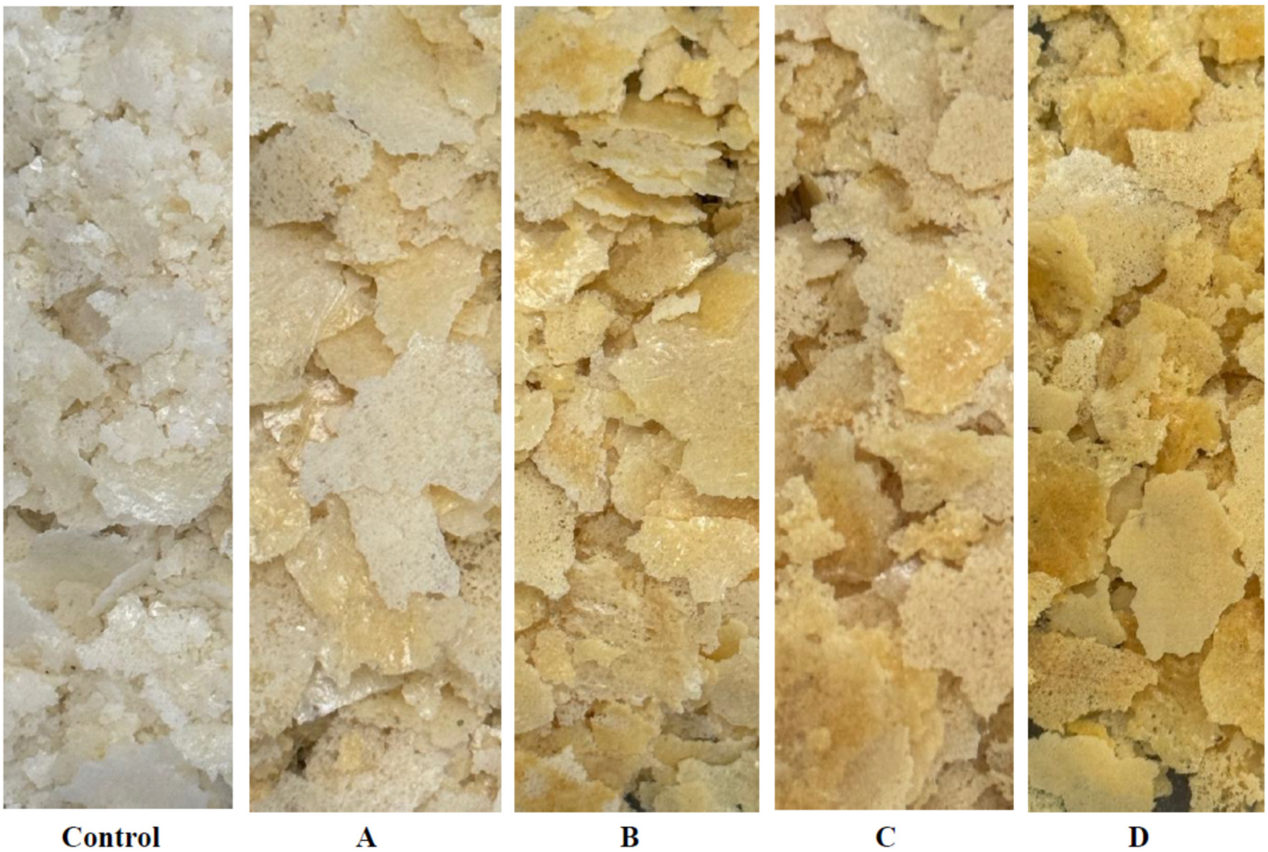

Figure 1. Visual colour comparison of drum-dried tarap-based breakfast cereal formulations with different levels of tarap pulp incorporation. Control: 0% tarap; A: 5% tarap; B: 10% tarap; C: 15% tarap; D: 20% tarap.

Total dietary fibre

Total dietary fibre was determined only for the control and the selected formulation (formulation D), which was chosen for further evaluation based on its highest overall sensory acceptability was presented in Table 4. The total dietary fibre values ranged from 4.66% to 4.85%, and no significant difference ($p > 0.05$) was observed between the control and formulation D.

Table 4. Total dietary fibre content (%) of the control and selected drum-dried tarap-based breakfast cereal formulation.

Formulation	Total dietary fiber (%)
Control	4.66 ± 1.49^{a}
D	4.85 ± 1.32^{a}

Values are presented as mean ± standard deviation ($n = 3$). Different lowercase letters within the same column indicate significant differences between the control and formulation D ($p < 0.05$). D: 20% tarap.

Sensory evaluation

The sensory evaluation results of the tarap-based cereal formulations are presented in Table 5. Significant differences ($p < 0.05$) were observed for most formulations for colour, taste, texture, and overall acceptability. The control sample recorded the lowest scores for all sensory attributes, with overall acceptability of 4.29 ± 1.58. Sensory scores increased with increasing levels of tarap incorporation. Formulation D obtained the highest scores for colour (7.47 ± 1.33), taste (6.93 ± 1.36), texture (7.56 ± 1.14), and overall acceptability (7.32 ± 1.24).

Table 5. Sensory evaluation scores of drum-dried tarap-based breakfast cereal formulations for colour, taste, texture, and overall acceptability.

Sample	Colour	Taste	Texture	Overall acceptability
Control	4.16 ± 1.66^{a}	4.20 ± 1.68^{a}	4.51 ± 1.92^{a}	4.29 ± 1.58^{a}
A	4.81 ± 1.56^{a}	5.17 ± 1.62^{b}	5.97 ± 1.79^{b}	5.37 ± 1.53^{b}
B	6.60 ± 1.59^{b}	6.16 ± 1.41^{c}	6.63 ± 1.45^{bc}	6.40 ± 1.40^{c}
C	7.28 ± 1.22^{c}	6.29 ± 1.67^{cd}	6.99 ± 1.31^{cd}	6.63 ± 1.44^{c}
D	7.47 ± 1.33^{c}	6.93 ± 1.36^{d}	7.56 ± 1.14^{d}	7.32 ± 1.24^{d}

Values are presented as mean ± standard deviation ($n = 3$). Different lowercase letters within the same column indicate significant differences among formulations ($p < 0.05$). A: 5% tarap; B: 10% tarap; C: 15% tarap; D: 20% tarap.

Shelf-life study

Based on the sensory evaluation results, formulation D (20% tarap pulp) was selected for the storage study and compared with the control formulation. Shelf-life study for the selected formulation D and control was conducted until 28 days after the drum drying process. The moisture content, a_w, and colour stability have been performed as shown in Table 6. Microbial counts were not determined in the present study; therefore, the storage results should be interpreted as preliminary physical stability data rather than a complete safety evaluation.

Moisture content

The moisture content of both samples changed during storage as shown in Table 6. In the control sample, moisture content increased from 2.61 ± 0.06% on day 0 to 4.65 ± 0.16% on day 7, followed by slight fluctuations until day 28, where it reached 4.26 ± 0.07%. Formulation D showed a similar pattern, increasing from 1.85 ± 0.06% on day 0 to 4.29 ± 0.69% on day 7, then decreasing slightly on days 14 and 21 before reaching 3.37 ± 0.01% on day 28. Overall, formulation D maintained lower moisture content than the control throughout the storage period.

Water activity (a_w)

The a_w values of both the control and formulation D remained low during the 28-day storage period, ranging between 0.18 and 0.23. The control sample recorded a_w values of 0.22, 0.18, 0.19, 0.23, and 0.22 on

Table 6. Changes in moisture content, water activity, and colour stability of the control and formulation D during 28 days of ambient storage.

Sample	Days	Moisture content (%)	Water activity (a_w)	Colour stability (ΔE*ab)
Control	0	2.61 ± 0.06	0.22 ± 0.01	0.00
	7	4.65 ± 0.16	0.18 ± 0.01	3.38
	14	4.30 ± 0.27	0.19 ± 0.02	2.62
	21	3.95 ± 0.43	0.23 ± 0.07	2.19
	28	4.26 ± 0.07	0.22 ± 0.05	1.96
D	0	1.85 ± 0.06	0.23 ± 0.00	0.00
	7	4.29 ± 0.69	0.18 ± 0.01	2.23
	14	3.14 ± 0.38	0.21 ± 0.01	2.69
	21	2.78 ± 0.09	0.19 ± 0.00	1.22
	28	3.37 ± 0.01	0.19 ± 0.02	0.37

D: 20% tarap.

days 0, 7, 14, 21, and 28, respectively, whereas formulation D showed values of 0.23, 0.18, 0.21, 0.19, and 0.19 over the same period. These findings indicate that only minor variations in a_w occurred during storage, and both samples retained low water availability throughout the study.

Colour stability

The total colour difference (ΔE*ab) increased in both samples during storage as presented in Table 6, indicating measurable colour changes over time. In the control sample, ΔE*ab increased to 3.38 on day 7 and gradually decreased to 1.96 on day 28. In formulation D, ΔE*ab reached 2.23 on day 7, slightly increased to 2.69 on day 14, and then decreased to 0.37 on day 28. At the end of storage, formulation D showed lower overall colour change than the control.

Discussion

Proximate composition

The proximate composition results indicate that the incorporation of tarap pulp influenced several nutritional components of the cereal formulations. The observed reduction in moisture content with increasing levels of tarap incorporation may be associated with changes in the composition of the cereal matrix during drum drying. The control formulation consisted mainly of brewer's rice, whose starch matrix tends to retain more moisture during gelatinization. In contrast, the addition of tarap pulp introduces non-starch solids, including dietary fiber and soluble sugars, which may reduce the water retention capacity of the matrix and promote more efficient moisture removal during drum drying [19].

The increase in ash content observed in the tarap-containing formulations suggests a greater mineral contribution from the fruit pulp. Tarap has been reported to contain appreciable levels of essential minerals such as potassium, iron, and zinc, which contribute to the overall ash content of food products [20]. Similar trends have been reported in composite cereal products where the incorporation of nutrient-rich ingredients increases the mineral content of the final product [21].

Only minor variation in protein content was observed among formulations, suggesting that tarap incorporation had a limited effect on the protein profile of the final product under the conditions tested. Although rice and rice by-products typically contain moderate protein levels ranging from approximately 7–18% on a dry basis, the addition of fruit components may contribute additional native proteins and nitrogen-containing compounds to the formulation [22]. Similar increases in protein content have been reported in cereal-based composite products formulated with fruit or legume flours [23]. Although some statistically significant differences were observed in ash and protein contents, the magnitude of these changes was relatively small. Therefore, the main contribution of tarap incorporation in this study appears to be related more to product diversification, sensory improvement, and valorization of local raw materials than to major enhancement of proximate nutritional composition.

The fat content showed minor variations among the formulations, which may be attributed to natural lipid components present in the tarap pulp. Fruit tissues may contain small amounts of lipid fractions that can influence the measured fat content of processed products. In addition, heat processing during drum drying may promote interactions between lipids and starch granules, potentially affecting lipid availability within the cereal matrix [24].

The higher total carbohydrate content observed in the tarap-containing formulations may be partly explained by the by-difference method used for carbohydrate calculation. Because carbohydrate was estimated by subtracting moisture, ash, protein, and fat from 100, the lower moisture content of formulations containing tarap pulp contributed to higher calculated carbohydrate values [16]. Furthermore, tarap pulp naturally contains simple sugars such as glucose and fructose that may contribute to the overall carbohydrate content of the cereal product. Although some statistically significant differences were observed among formulations, the magnitude of these changes was relatively small. Thus, the practical significance of tarap incorporation in this study appears to be related more to sensory improvement and utilization of local raw materials than to major enhancement of proximate nutritional composition.

Physicochemical properties

Water absorption capacity

Water absorption capacity is an important functional property that reflects the ability of cereal products to absorb and retain water during rehydration. The relatively high water absorption capacity values observed in the cereal formulations indicate good hydration capacity of the drum-dried cereal flakes. This behavior is primarily associated with starch gelatinization occurring during the drum drying process. Thermal treatment disrupts the crystalline structure of starch granules and increases the availability of hydrophilic sites capable of binding water [25].

The absence of significant differences in water absorption capacity among the formulations suggests that the addition of tarap pulp did not substantially alter the water-binding capacity of the cereal matrix. This may be due to compensatory interactions between starch and dietary fiber components. While dietary fibers possess water-binding capacity through hydrogen bonding interactions, the structural integrity of the cereal flakes may have maintained similar hydration characteristics across the different formulations [26].

Colour characteristics

Colour analysis revealed that the incorporation of tarap pulp significantly influenced the appearance of the cereal flakes. Samples containing higher proportions of tarap exhibited lower lightness (L*) values and higher redness (a*) and yellowness (b*) values. This indicates that the addition of tarap resulted in darker and more intensely coloured cereal flakes.

These colour changes can be attributed to several factors. First, natural pigments present in fruit pulp, including carotenoids and other coloured phytochemicals, can contribute to the observed colour characteristics of fruit-enriched cereal products [27]. Second, non-enzymatic browning reactions, particularly the Maillard reaction between reducing sugars and amino acids, may occur during thermal processing such as drum drying. Such reactions are common in fruit-containing food systems where natural sugars are present in relatively high concentrations [11]. Similar colour development has been reported in cereal products enriched with fruit powders or fruit-derived ingredients.

Total dietary fibre

The total dietary fibre content did not differ significantly between the control and formulation D. Although tarap is a fruit and may be expected to contribute fibre, several factors may explain this result. First, the edible pulp used in this study may have contained a relatively modest amount of insoluble fibre compared with other structural fruit fractions such as peel or seed. Second, the level of tarap pulp incorporated into the cereal formulation may not have been high enough to produce a statistically detectable increase in the total dietary fibre content of the final product. In addition, because the cereal matrix was still dominated by brewer's rice, the overall fibre contribution from tarap pulp may have been diluted within the formulation. Thermal processing during drum drying may also have affected the structure, distribution, or extractability of fibre components, thereby reducing the apparent difference in measured total dietary fibre between samples. Therefore, the absence of a significant difference in total dietary fibre does not necessarily indicate that tarap pulp contributed no fibre, but rather that its contribution was not sufficiently large to be detected under the present formulation and processing conditions. Similar observations have been reported in cereal products where moderate incorporation of fruit ingredients resulted in only marginal changes in dietary fiber content [26].

Sensory evaluation

Sensory evaluation results demonstrated that the addition of tarap pulp positively influenced consumer acceptance of the cereal product. Formulations containing tarap consistently received higher scores for colour, taste, texture, and overall acceptability compared with the control sample. These results indicate that the incorporation of tarap contributes beneficial sensory characteristics to the cereal product.

Tarap pulp contains natural sugars, volatile flavour compounds, and pigments that may enhance the flavour profile and visual appeal of the cereal. The pleasant aroma and sweetness of the fruit are likely to contribute to improved taste perception among panelists. Furthermore, structural changes occurring during drum drying may influence the texture of the cereal flakes. Thermal processing can produce porous structures within the cereal matrix, which contribute to desirable crispness and fracture characteristics in cereal products [28].

Although increasing the level of fruit incorporation may further enhance flavour attributes, excessively high levels of fruit pulp could potentially lead to undesirable sensory effects. High sugar concentrations may promote excessive browning reactions during thermal processing, resulting in darker colour or burnt flavour notes. Therefore, the 20% tarap formulation appears to represent a suitable balance between flavour enhancement, colour development, and desirable texture characteristics.

Shelf-life stability

The shelf-life study showed that both the control and formulation D remained relatively stable during 28 days of storage under ambient conditions. However, the changes observed in moisture content, a_w, and colour stability suggest some differences in storage behaviour between the two samples. The storage study was designed as a preliminary real-time ambient assessment rather than an accelerated shelf-life study. Future work should incorporate accelerated storage conditions together with microbiological, oxidative, textural and sensory analyses over a longer storage duration to support more robust shelf-life prediction.

Moisture content in both samples increased markedly during the first 7 days of storage, which is consistent with the hygroscopic nature of cereal-based products. Low-moisture foods tend to absorb water from the surrounding environment until equilibrium is approached, especially when stored under ambient conditions [29]. After day 7, the moisture contents of both samples fluctuated rather than showing a continuous increase. This pattern may reflect variations in moisture redistribution within the product matrix and interactions between the cereal components and the surrounding environment during storage. Notably, formulation D consistently showed lower moisture content than the control, suggesting that tarap incorporation may have contributed to a matrix that was less prone to moisture retention during storage.

Although moisture content changed over time, a_w remained low in both samples, with values ranging only from 0.18 to 0.23. This confirms that the water present in the product was largely in a bound state rather than freely available for microbial growth. The low a_w values observed throughout storage suggest limited water availability, which may reduce the likelihood of microbial proliferation, as most bacteria, yeasts, and moulds generally require higher a_w values for growth [30]. However, microbiological safety cannot be confirmed based on a_w and physical analyses alone. Therefore, microbial enumeration and pathogen screening should be conducted in future studies to verify the safety of the product before food application or commercialization.

The colour stability results showed that both samples underwent some degree of colour change during storage, particularly in the early stage. The higher ΔE*ab values observed on day 7 suggest that colour changes were more pronounced during the initial storage period. This may be related to early oxidative or non-enzymatic browning reactions in the cereal matrix. However, the lower ΔE*ab values observed at day 28 indicate that the rate of colour change decreased over time. Formulation D exhibited a much lower ΔE*ab value than the control at the end of storage, suggesting better colour stability. This may be associated with the presence of natural antioxidant compounds in tarap, such as phenolics and flavonoids, which could help reduce oxidative deterioration and preserve product appearance during storage [7].

Overall, although the incorporation of tarap improved sensory acceptability and influenced selected physicochemical properties, some nutritional changes, particularly total dietary fibre and protein content, were relatively modest. Therefore, the findings should be interpreted mainly in terms of product diversification, sensory improvement, and valorization of local raw materials rather than major nutritional enhancement. The present storage study should also be interpreted as a preliminary physical stability assessment. Further microbiological analysis, including total plate count, yeast and mould count, and relevant pathogen screening, is required to confirm product safety. In addition, longer-term storage studies incorporating oxidative stability, texture retention, and sensory quality evaluation should be conducted to provide a more comprehensive assessment of shelf-life performance.

Conclusion

This study showed that tarap can be successfully incorporated into a drum-dried breakfast cereal using brewer's rice as the main base ingredient. The addition of tarap influenced several important product characteristics, including proximate composition, colour, and sensory quality, while maintaining low moisture content and a_w suitable for ambient storage. Among the formulations tested, formulation D was the most acceptable, indicating that 20% tarap incorporation provided the selected balance of colour, taste, texture, and overall consumer preference. The selected formulation maintained low water activity and relatively stable physical characteristics over 28 days of ambient storage, indicating promising short-term storage stability. Overall, the findings support the potential of tarap and brewer's rice as promising ingredients for the development of value-added and sensory acceptable ready-to-eat cereal products, particularly from the perspectives of sensory quality and local raw material utilization. Nevertheless, the present study only assessed physicochemical properties, sensory acceptability, and preliminary storage stability. Microbiological safety, longer-term shelf-life performance, oxidative stability, and sensory quality during storage must be further verified before the product can be recommended for future food application or commercialization.

Declarations

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Author contributions

HYT: Conceptualization, Investigation, Writing—original draft. HM: Validation, Writing—review & editing. WP: Validation. JR: Investigation. MTML: Visualization, Formal analysis. MIMR: Resources, Data curation. MSMS: Writing—review & editing. NRP: Methodology, Validation. ANMF: Formal analysis, Visualization. LMS: Writing—original draft. EG: Resources. AHAA: Supervision, Project administration, Funding acquisition. All authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

The sensory evaluation involving human participants was conducted in accordance with the Declaration of Helsinki and was reviewed and approved by the Medical Research Ethics Committee, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah (Approval code: JKEtika 5/25 (68)). All participants were informed about the purpose of the study and participated voluntarily, and provided informed consent prior to the sensory evaluation.

Consent to participate

Informed consent was obtained from all panelists prior to the sensory evaluation.

Consent to publication

Not applicable.

Availability of data and materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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References

1. Bhavya S, Prakash J. Nutritional composition and quality of whole grain ready-to-eat breakfast cereals. Indian J Nutr Diet. 2012;49:417–25.
2. Smith J, Jain N, Normington J, Holschuh N, Zhu Y. Associations of Ready-to-Eat Cereal Consumption and Income with Dietary Outcomes: Results from the National Health and Nutrition Examination Survey 2015–2018. Front Nutr. 2022;9:816548. [DOI] [PubMed] [PMC]
3. Michels N, De Henauw S, Beghin L, Cuenca-García M, Gonzalez-Gross M, Hallstrom L, et al. Ready-to-eat cereals improve nutrient, milk and fruit intake at breakfast in European adolescents. Eur J Nutr. 2015;55:771–9. [DOI] [PubMed] [PMC]
4. Quiles A, Campbell GM, Struck S, Rohm H, Hernando I. Fiber from fruit pomace: A review of applications in cereal-based products. Food Rev Int. 2016;34:162–81. [DOI]
5. Masri N, Mansoor A, Mamat H. Proximate composition, mineral content and functional properties of Tarap (*Artocarpus odoratissimus*) seed flour. Food Res. 2017;1:89–96. [DOI]
6. Jonatas KAS, Querequincia JMB, Miranda SD, Obatavwe U, Corpuz MJ, Vasquez RD. Antidiabetic evaluation of *Artocarpus odoratissimus* (Moraceae) fruit. J Ilm Farm. 2020;16:1–8. [DOI]
7. Yulianti I, Padlilah R, Ariyanti R, Retnowati Y, Febrianti S, Purnamasari A. Mapping review of the potential of Tarap Plants (*Artocarpus odoratissimus*) for health. Int J Health Sci. 2022:2351–7. [DOI]

8. Tan BL, Norhaizan ME, Hairuszah I, Hazilawati H, Roselina K. Brewers' Rice: A By-Product from Rice Processing Provides Natural Hepatorenal Protection in Azoxymethane-Induced Oxidative Stress in Rats. Oxidative Med Cell Longev. 2015;2015:539798. [DOI] [PubMed] [PMC]
9. Nordin N, Karim R, Ghazali HM, Adzahan NM, Sultan MT. Effects of various stabilization techniques on the nutritional quality and antioxidant potential of brewer's rice. J Eng Sci Technol. 2014;9:347–63.
10. Karthik P, Chhanwal N, Anandharamakrishnan C. Drum Drying. In: Handbook of Drying for Dairy Products. John Wiley & Sons Ltd; 2017. pp. 43–56. [DOI]
11. Desobry SA, Netto FM, Labuza TP. Comparison of Spray-drying, Drum-drying and Freeze-drying for β-Carotene Encapsulation and Preservation. J Food Sci. 2006;62:1158–62. [DOI]
12. Billah MT, Hossain MA, Zannat NE, Roy J, Sarker MSH. Integrated design and optimization of a conceptual double drum dryer for drying of wheat flour slurry: Experimental validation and computational analysis. J Food Process Eng. 2024;47:e14701. [DOI]
13. Okoye JI, Ahmadu DL, Egbujie AE. Evaluation of proximate composition, functional and pasting properties of millet-based breakfast cereals supplemented with soybean and date fruit flours. Int J Sch Res Eng Technol. 2023;2:060–70. [DOI]
14. Yang CZ, Khurun Hizar SA, Ronie ME, Mamat H, Mohd Amin SF, Mohammad Ridhwan N, et al. Nutritional, functional, and sensory evaluation of corn-based instant cereal enriched with chickpea and carrot produced by drum drying. Explor Foods Foodomics. 2026;4:1010123. [DOI]
15. AOAC. Official methods of analysis of the Association of Official Analytical Chemists. AOAC; 2000.
16. McCleary BV, McLoughlin C. Measurement of Available Carbohydrates in Cereal and Cereal Products, Dairy Products, Vegetables, Fruit, and Related Food Products and Animal Feeds: First Action 2020.07. J AOAC INT. 2021;104:1465–78. [DOI] [PubMed] [PMC]
17. Goh SX, Mamat H, Abdul Aziz AH. Valorization of agriculture by-product: Development of gluten-free biscuit made from blends of okara and jackfruit seed flour. Waste Manag Bull. 2024;2:59–65. [DOI]
18. Ling CLH, Mamat H, Abdul Aziz AH, Zainol MK, Mohammad Ridwan N. Developing Healthier Biscuit Alternatives: An Analysis of Tapioca, Desiccated Coconut, and Wheat Flour Blends. Int J Food. 2024;1: 1–10. [DOI]
19. Zhang Y, Zhang J, Wang Z, Fan L, Chen Y. Effect of Rice Protein on the Gelatinization and Retrogradation of Rice Starch with Different Moisture Content. Foods. 2024;13:3734. [DOI] [PubMed] [PMC]
20. Adepeju AB, Aluko DM, Olugbuyi AO, Oyinloye AM, Adeniran OO. Assessment of mineral content, techno-functional properties and colour of an extruded breakfast cereals using yellow maize, sorghum and date palm. Heliyon. 2024;10:e27650. [DOI] [PubMed] [PMC]
21. Saraswati L, Azima F, Syukri D. Characterization of Flakes Made in Corn Flour (*Zea Mays*) and Pumpkin (*Cucurbita Moshcata*) with Addition of Soybean Flour (*Glicine Max*). Andalasian Int J Agric Nat Sci (AIJANS). 2022;3:42–66. [DOI]
22. Poutanen KS, Kårlund AO, Gómez-Gallego C, Johansson DP, Scheers NM, Marklinder IM, et al. Grains – a major source of sustainable protein for health. Nutr Rev. 2022;80:1648–63. [DOI] [PubMed] [PMC]
23. Sunday OK, Onyinye MC, Nneka MG, Bibiana AC, Ishiwu C. N., Miracle EA. Response Surface Methodology Approach for the Production of Enriched Rice-based Breakfast Cereal. Asian Food Sci J. 2023;22:48–59. [DOI]
24. Collar C, Armero E. Lipid composition and dynamics during breadmaking in heat-moisture-treated associated matrices. Eur Food Res Technol. 2019;245:2413–24. [DOI]
25. Singh S, Gamlath S, Wakeling L. Nutritional aspects of food extrusion: a review. Int J Food Sci Technol. 2007;42:916–29. [DOI]
26. Elleuch M, Bedigian D, Roiseux O, Besbes S, Blecker C, Attia H. Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. Food Chem. 2011;124:411–21. [DOI]

27. Nazir F, Naik H, Hussain S. Effect of Extrusion Conditions and Apricot Powder Incorporation on Colour Parameters of Rice Based Breakfast Snacks. Biosci Biotechnol Res Asia. 2016;13:1673–8. [DOI]
28. Blejan AM, Nour V, Corbu AR, Codină GG. Corn-Based Extruded Snacks Supplemented with Bilberry Pomace Powder: Physical, Chemical, Functional, and Sensory Properties. Appl Sci. 2025;15:2468. [DOI]
29. Jo Y, Kim E, Kim S, Ban C, Lim S. Delayed Quality Deterioration of Low-Moisture Cereal-Based Snack by Storing in an Active Filler-Embedded LDPE Zipper Bag. Foods. 2022;11:1704. [DOI] [PubMed] [PMC]
30. Jay JM, Loessner MJ, Golden DA. Modern Food Microbiology. New York: Springer; 2005. [DOI]