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Comparison of Changes in Different Characteristics of Arrowroot (*Maranta arundinacea*) Flour Stored under Ambient (27 °C) and Refrigerated (4 °C) Conditions

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Abstract

Arrowroot (*Maranta arundincea*) is an underutilized gluten-free flour source in Sri Lanka. The purpose of this study was aimed to evaluate the physicochemical properties and microbiological safety of arrowroot flour while it was stored at room temperature (27 °C) and refrigerated (4 °C) for a year. Moisture content (%), water activity (aw), colour in L*a*b* values, and microbial load (log cfu/g) were assessed. Before storage, arrowroot flour was extracted from rhizomes and packed into LDPE bags. The moisture content, water activity, and colour of arrowroot flour were found to be significantly affected by storage conditions. The moisture content and water activity of flour stored under both conditions increased, while L* values decreased over time. Microbial growth was also observed, with ambient storage having a higher microbial load than refrigerated storage. The study contributes to the development of quality standards for arrowroot flour by providing important information on its shelf life. It also emphasizes the significance of refrigerated storage conditions to ensure the safety and quality of arrowroot flour for consumption.

Keywords: *Arrowroot, Colour, Maranta arundinacea, Microbiological assessment, Water activity*

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Introduction

Starch is the primary source of carbohydrates in plants and an essential component of the diet. It is a useful ingredient in the food industry for a variety of purposes. Starch is found in the amyloplasts of storage organs such as seeds and tubers, as well as in the leaf chloroplasts of higher plants, as a primary carbohydrate reserve. Maize, potato, wheat, and cassava are the most important crops for starch production worldwide, with smaller amounts coming from sorghum, rice, sweet potato, sago, arrowroot, and mung beans (Vongpichayapaiboon *et al*., 2016).

Arrowroot (*Maranta arundinacea*; Family: Marantacea) is a herbaceous, underutilized tuber crop with horizontally spreading rhizomes that emit roots, leaves, and branches from their knots. The rhizome of arrowroot contains 20% starch, of which 20 - 30% is amylose, depending on the age of the plant (Amante *et al*., 2021). Arrowroot, also known as "Hulankeeriya" or "Aerukka" in Sri Lanka, is a soothing agent and treatment for digestive issues in folk and Ayurvedic medicine. Its use in the food industry is limited to porridge, boiled rhizomes with grated coconut, and curry due to its limited availability and time-consuming flour extraction process, but it is a gluten-free alternative to wheat flour (Malki *et al*., 2022).

The quality of the flour may be destroyed if stored for an extended period. The acidity and pH of cereals and cereal products are affected by grain moisture content, humidity, and storage temperature (Huyghcbact and Schoner, 1999). Changes in the chemical composition of flour have made biochemical and nutritional quality control of stored products increasingly important (Rehman, 2006).

Moisture is also important for the safe storage of cereals and their products in terms of microorganisms, particularly certain fungi species (Hoseney, 1994). According to previous research, the amount of moisture in food products determines their shelf life. This is because the moisture content of the food product affects microbial spoilage as well as certain food chemical reactions (Rawat, 2015).

Water activity is defined as the ratio of its vapour pressure when in complete equilibrium with the surrounding air media to the vapour pressure of distilled water under identical conditions (U.S. Food and Drug Administration, 1984). It refers to the amount of water available for microbial growth in a portion of food (Fontana, 2008). Water activity predicts food stability (Ukegbu and Anyika, 2012).

Colour of flour is an important feature that will affect the final appearance of bakery food products when replacing wheat flour with arrowroot flour or when creating new arrowroot flour products. A consumer's first consideration when evaluating food is its colour (Spence, 2015). The CIE (International Commission on Illumination) L*a*b* colour space is the most commonly used when it comes to food because of its uniform colour distribution and colour perception that is closest to that of the naked human eye (Markovic *et al*., 2013). Lightness, brightness, saturation, hue, chroma, and colourfulness are all determined by L*a*b* readings (Macdougall, 2002).

The purpose of this study was to compare the changes in physicochemical properties and microbiological safety of arrowroot flour over a year in both stored under ambient (27°C) and refrigerated (4 °C) conditions. This study specifically focused on evaluating changes in moisture content, water activity, colour, and microbial load of arrowroot flour during storage to predict the best storage conditions for arrowroot flour.

Materials and Methods

Arrowroot Flour Preparation

Arrowroot rhizomes were collected from home gardens in Sri Lanka.

Minor modifications were made to the extraction of arrowroot flour described by Nogueira et al. (2018). The arrowroot rhizomes were peeled, cut, and cleaned. They were then crushed for 5 minutes in a high-speed stainless steel blender (Preethi MG172 E, Preethi Electrical Appliances, India) to form a homogeneous mass with tap water and arrowroot in a 1: 2 (w/v) ratio. Double cotton cloth was used to filter the resulting mixture. Following overnight flour sedimentation, water was manually separated. The flour was oven dried for 8 to 10 hours at 60 °C with air circulation in a dry oven (Memmert UN 160, Germany) before being ground in a grinder (Preethi MG-172 E, Pethi Electrical Appliances, India). The extracted flour was sieved (425 µm), packed into LDPE bags, and stored at ambient (27 °C) and refrigerated (4 °C) conditions.

Determination of Moisture Content

The percentage of moisture was determined using a digital moisture analyzer (Infrared Moisture Analyzer Kett FDinto Kett, Japan). Five grams of flour samples were placed in the pan and microwave-assisted heating was used to determine the moisture content. For a year, measurements were taken once a month.

Determination of Water Activity

Water activity was measured using a water activity meter (Novasina MS1, India). Plastic cans were filled with flour samples and set, and the value was displayed on the screen. For one year, measurements were taken once a month.

Determination of Flour Colour

Colourimeter (PCE-CSM 2, PCE Instruments, United States) was used to evaluate the colour of arrowroot flour. Using the provided calibration disc, the colourimeter was calibrated and colour coordinates were recorded. The sample surfaces were flattened in watch glass before use. A piece of clear polythene was placed over the prepared samples before the colourimeter's measurement head was placed on them. The colour coordinates of L*a*b* values were used to derive the colour charatecristics of L* (L* = 0 for black and L* = 100 for white), a* (-a for greenness and +a for redness), and b* (-b for blueness and +b for yellowness) (Malki *et al*., 2022). Colour measurements were taken once a month for one year.

Microbiological Assessment

Yeast and mold count and total plate count were measured once in three months by making slight changes to Tadesse *et al*. (2015). Potato dextrose agar media was used for yeast and mould count, while total plate count agar was used for total mould count measurement. A dilution series up to 10^{-5} was prepared. After 48 hours, the counts were taken. For one year, counts were taken once every three months.

Statistical Analysis

The measurements were taken in triplicate. Using the Minitab statistical software, the results were analyzed using analysis of variance (ANOVA) at the 0.05 significance level (version 19).

Results and Discussion

Moisture Content and Water Activity of Arrowroot flour during Storage

Moisture content is a critical factor in shelf life evaluations. Variations of moisture content and water activity with time for arrowroot flour stored under ambient and refrigerated conditions are presented in Table 1.

This study has shown that thermostable polyphenol oxidase can be isolated from African star apple juice under viable conditions. Higher activities of polyphenol oxidase and antioxidant enzymes like SOD, CAT and GSH level were observed in the juice at week 4 stored under refrigerated temperature. The study also provided a database on the effect of temperature, pH and thermal stability on polyphenol oxidase activities in juice extracted from African star apple. Therefore, this indicates that African star apple can be used as an excellent raw material for isolation of these enzymes industrially. The contributions of both biological and chemical preservatives, in conjunction with different packaging materials on polyphenol oxidase activities, should be further investigated.

Moisture content increased gradually in both storage conditions, but moisture increment in refrigerated conditions is significantly lower than in ambient conditions (Table 1). The final moisture content of arrowroot flour under ambient conditions was 14.16±0.15% and 12.40±0.26% under refrigerated conditions. Moisture increment in refrigerated storage is significantly lower than in ambient storage, demonstrating the effectiveness of refrigerated storage in extending shelf life. However, after a year, arrowroot flour stored under both conditions had not exceeded the acceptable moisture content (15%) for consumption (Reddy *et al*., 2017). The moisture content directly affects the shelf life of flour; the lower the moisture content will enhance the shelf life (Nazir *et al*., 2003). According to the results, there was a rapid increase in moisture during the initial stage of storage, and the same phenomenon was observed by Ojo *et al*. (2017) for the shelf life estimation of some selected grain flours. Moisture content has a direct impact on the microbial growth and shelf life of flour (Ojo *et al*., 2017). Refrigerated storage was identified as the best storage condition for arrowroot flour based on moisture content results.

The water activity (aw) of flour samples increased over time under both storing conditions, but there was a rapid increase under ambient storage than refrigerated storage. The water activity values of both flours were less than the value (0.91) required for most food spoilage bacteria to grow (Sivasankar, 2010). The final water activity levels of refrigerated arrowroot flour and ambient stored arrowroot flour were respectively 0.43±0.02 and 0.51±0.00. The water activity results also reveal that refrigerated storage is the best storage condition for arrowroot flour.

Arrowroot Flour Colour during Storage

Arrowroot flour showed a decrease in L* values (lightness) over time, which is indicated by the lower values at the end of the storage period. However, the amount of the decrease varied between ambient and refrigerated storage conditions. For instance, the final L* value of the refrigerated arrowroot flour after one year of the period was 96.81±0.54 and it was significantly higher ($P<0.05$) than the ambient stored arrowroot flour (95.91±0.43), indicating better colour stability under refrigerated storage.

Regarding the a* and b* values, they represent redness and yellowness, respectively. Fluctuations in these values were observed in those values over time, but no clear trends were observed. However, there were significant differences between the ambient and refrigerated flours for these colour parameters, indicating that storage temperature has a significant impact on the colour stability of the arrowroot flour. According to a study conducted by Wijesinghe *et al*. (2015) for *Kithul* flour, there was an increment in lightness (L*) but a* and b* values were not significantly changed after one year time period under refrigerated (4 °C) storage. The storage temperature and period significantly affect the colour stability of the arrowroot flour. Refrigeration is a more suitable storage condition for maintaining the colour stability of arrowroot flour. Variation of Arrowroot flour colour with time is presented in Table 2.

Microbiological Assessment of Arrowroot Flour during Storage

After three months, the difference between the two storage conditions became significant. The total plate count increased steadily over time and reached the highest level at month 12. Temperature, water activity, pH, and the presence of antimicrobial compounds all influenced microbial growth (Hamad, 2012). However, after one year of storage under both conditions, the total viable counts were within the acceptable limits of 10^7 cfu/g (ICMSF, 1996) for flours and yeast, and the mould counts were less than 10^3 cfu/g. The increase in microbial growth in flour samples stored at room temperature is attributed to favourable microbial growth conditions, such as high temperature and humidity. The increased water activity in flour samples stored at room temperature promotes microbial growth. Refrigerated storage is recommended to maintain the quality and safety of arrowroot flour for a longer duration. Variation of total plate count (log cfu/g) is presented in Table 3.

Table 1: Variation of moisture content and water activity of arrowroot flour colour with time

Month	Moisture content (%)		Water activity (aw)	
	Ambient (27 °C)	Refrigerated (4 °C)	Ambient (27 °C)	Refrigerated (4 °C)
Month 1	9.36±0.98^{e}	9.36±0.98^{d}	0.19±0.00^{i}	0.19±0.00^{f}
Month 2	11.36±0.45^{d}	10.03±0.11^{cd}	0.39±0.02^{h}	0.31±0.00^{d}
Month 3	12.33±0.15^{cd}	11.03±0.72^{bc}	0.49±0.00^{fg}	0.36±0.03^{bcd}
Month 4	13.00±0.17^{bc}	10.80±0.36^{bc}	0.53±0.01^{def}	0.37±0.00^{bc}
Month 5	13.63±0.51^{ab}	11.03±0.15^{bc}	0.55±0.02^{cde}	0.34±0.01^{cd}
Month 6	14.70±0.43^{a}	11.60±0.20^{ab}	0.61±0.00^{ab}	0.26±0.00^{e}
Month 7	14.20±0.36^{ab}	11.10±0.10^{abc}	0.59±0.01^{abc}	0.33±0.02^{cd}
Month 8	14.16±0.47^{ab}	11.36±0.28^{ab}	0.57±0.00^{bcd}	0.44±0.00^{a}
Month 9	14.06±0.05^{ab}	11.10±0.10^{abc}	0.52±0.03^{efg}	0.40±0.03^{ab}
Month 10	13.80±0.17^{ab}	10.90±0.69^{bc}	0.47±0.00^{g}	0.34±0.00^{cd}
Month 11	14.26±0.25^{ab}	11.33±0.28^{abc}	0.62±0.00^{a}	0.43±0.00^{a}
Month 12	14.16±0.15^{ab}	12.40±0.26^{a}	0.51±0.00^{efg}	0.43±0.02^{a}

Mean±SD; n = 3; Between rows, mean values followed by different superscript letters are significantly different at p = 0.05.

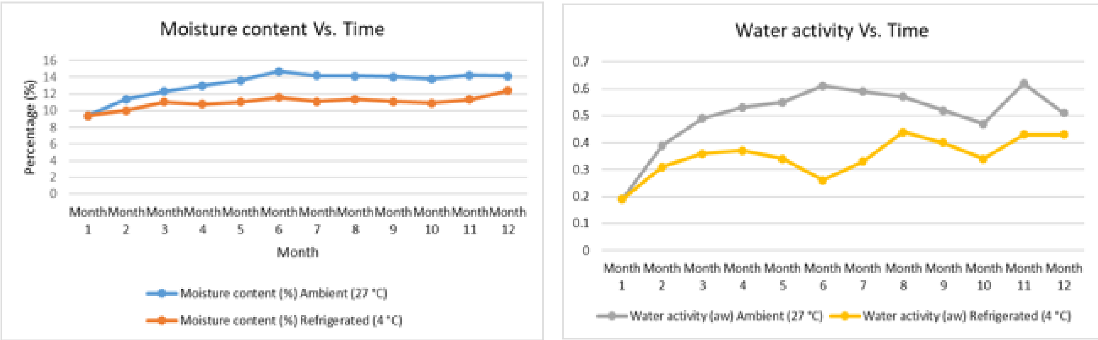

Figure 1: Variation of moisture content and water activity of arrowroot flour under ambient (27 °C) and refrigerated (4 °C) storing conditions

Table 2: Variation of arrowroot flour colour with time

Month	L*		a*		b*	
	Ambient (27 °C)	Refrigerated (4 °C)	Ambient (27 °C)	Refrigerated (4 °C)	Ambient (27 °C)	Refrigerated (4 °C)
Month 1	92.69±0.77^{c}	92.69±0.77^{b}	1.07±0.11^{a}	1.07±0.11^{a}	5.52±0.13^{c}	5.52±0.13^{abc}
Month 2	93.23±1.67^{bc}	93.48±0.68^{ab}	0.85±0.04^{ab}	0.77±0.11^{ab}	5.44±0.41^{c}	5.24±0.27^{c}
Month 3	95.69±0.96^{ab}	95.30±1.02^{ab}	0.71±0.04^{bc}	0.67±0.12^{b}	5.86±0.33^{abc}	5.92±0.33^{ab}
Month 4	95.99±0.28^{a}	94.98±0.30^{ab}	0.67±0.05^{bc}	0.66±0.05^{b}	6.00±0.11^{abc}	5.67±0.08^{abc}
Month 5	95.11±0.71^{abc}	95.23±1.00^{ab}	0.51±0.03^{c}	0.57±0.07^{b}	5.78±0.45^{bc}	5.41±0.26^{bc}
Month 6	96.03±1.41^{a}	95.14±0.49^{ab}	0.78±0.08^{b}	0.71±0.09^{b}	6.17±0.14^{abc}	5.70±0.01^{abc}
Month 7	94.90±0.79^{abc}	96.43±2.65^{a}	0.80±0.03^{b}	0.76±0.07^{ab}	6.51±0.40^{ab}	5.59±0.21^{abc}
Month 8	94.71±1.20^{abc}	95.47±2.05^{ab}	0.85±0.12^{ab}	0.80±0.28^{ab}	6.23±0.28^{abc}	5.58±0.32^{abc}
Month 9	94.36±0.25^{abc}	95.46±0.28^{ab}	0.82±0.06^{b}	0.65±0.03^{b}	6.00±0.26^{abc}	5.49±0.15^{abc}
Month 10	95.79±0.53^{ab}	96.08±1.14^{ab}	0.84±0.09^{ab}	0.75±0.07^{ab}	5.96±0.12^{abc}	5.50±0.32^{abc}
Month 11	94.35±0.16^{abc}	97.78±0.10^{ab}	0.73±0.04^{bc}	0.81±0.00^{ab}	6.36±0.20^{ab}	5.61±0.05^{abc}
Month 12	95.91±0.43^{a}	96.81±0.54^{a}	0.83±0.12^{b}	0.67±0.13^{b}	6.62±0.16^{a}	6.11±0.07^{abc}

Mean±SD; n = 3; L = Lighness, a*=redness or greenness, b*=yellowness or blueness*
Between rows, mean values followed by different superscript letters are significantly different at p = 0.05

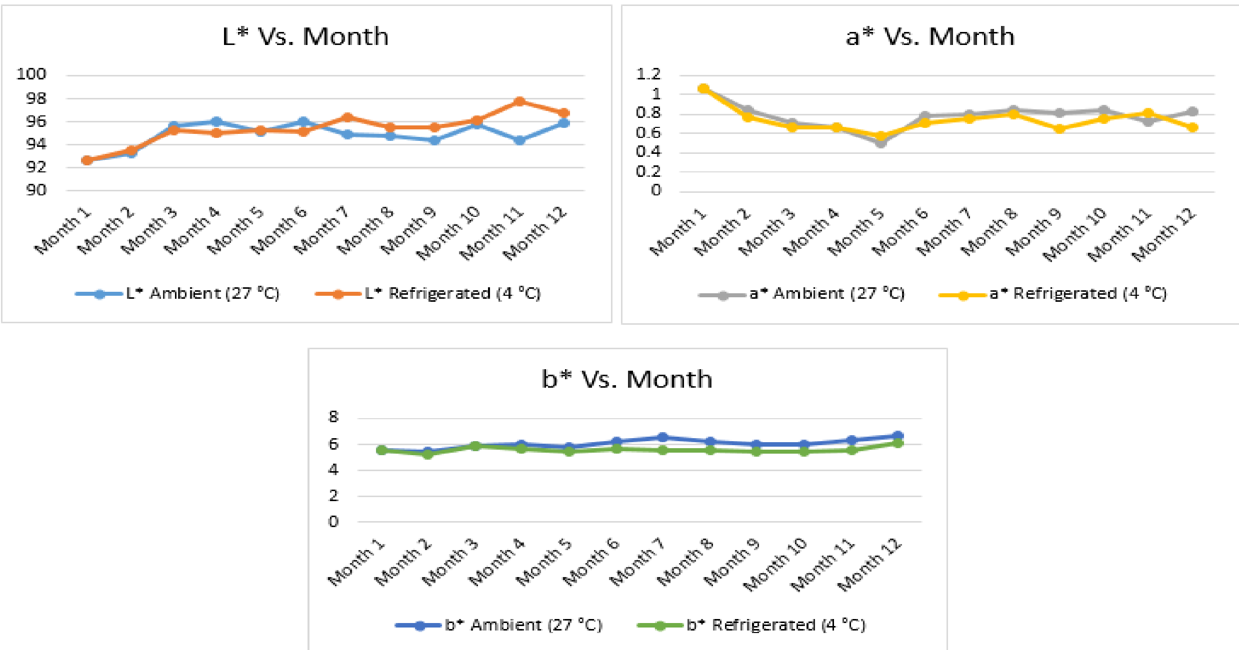

Figure 2: Variation of colour attributes (L*, a*, b*) of arrowroot flour under ambient (27 °C) and refrigerated (4 °C) storing conditions.

Table 3: Variation of total plate count (log cfu/g) with time

Month	Total plate count (log cfu/g)	
	Ambient (27 °C)	Refrigerated (4 °C)
Month 1	4.07±0.67[c]	4.07±0.67[b]
Month 3	4.85±0.13[c]	3.86±0.07[b]
Month 6	5.78±0.16[b]	4.46±0.20[b]
Month 9	5.89±0.06[b]	4.33±0.23[b]
Month 12	6.91±0.05[a]	5.82±0.03[b]

Mean±SD; n = 3
Between rows, mean values followed by different superscript letters are significantly different at p = 0.05

Conclusion

Shelf life of arrowroot flour has been studied for a period of one year. The moisture content of the arrowroot flour increased during storage, with the greatest increase observed in samples stored at ambient conditions. The colour of the arrowroot flour changed during storage, with a significant decrease in L* value observed in both ambient and refrigerated storage conditions. The microbial load of arrowroot flour increased during storage, with the greatest increase observed in samples stored at ambient conditions. This increase in microbial load could be attributed to the high moisture content and water activity of the flour, which provided favourable conditions for microbial growth. The results of this study state that the storage conditions of arrowroot flour significantly affect its physicochemical properties and microbial safety. The increase in moisture content and water activity, as well as the decrease in L* value and increase in microbial load, suggest that the shelf life of arrowroot flour is limited, particularly when stored at ambient conditions and refrigerated storage was identified as the best storage condition for arrowroot flour to extend the shelf life.

Declarations

Competing Interest

The authors declare no competing interest.

Authors' Contributions

All listed authors contributed equally to the literature writing, review, research process and editing of this article.

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