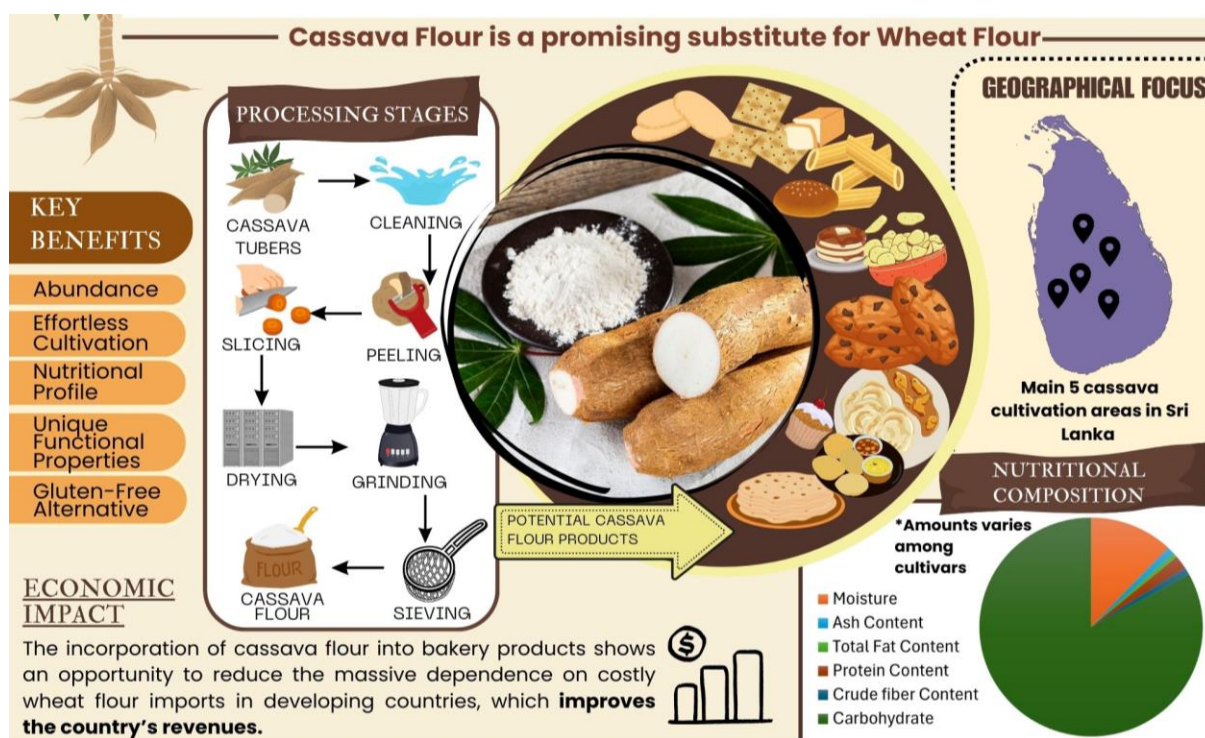


Cassava Flour as a Possible Replacement for Wheat Flour: A Comprehensive Review Considering the Sri Lankan Scenario

S.M.C.N. Senanayake¹, M.A. Jayasinghe^{1*}, M.A. D. Somendrika¹, C. Jayathilake² and R.S. Diyabalanage³

¹Department of Food Science and Technology, Faculty of Applied Sciences, University of Sri Jayewardenepura, Sri Lanka. ²School of Medicine, Case Western Reserve University, Cleveland, Ohio, USA. ³Instrument Centre, Faculty of Applied Sciences, University of Sri Jayewardenepura, Sri Lanka

Date Received: 21-03-2024 Date Accepted: 28-06-2024



Abstract

Cassava (*Manihot esculenta*) is a long tuberous starch-containing root crop that stands as a significant staple food globally. Its adaptability to various climates has increased its commercial growth. However, challenges such as toxic cyanogenic glucosides and rapid perishability in cassava demand its processing for safety and extended shelf-life. In Sri Lanka, where cassava is widely consumed, surplus production can be a highly prospective revenue. This review summarizes the utilization of cassava flour as a potential alternative for wheat flour emphasizing the Sri Lankan scenario. The cassava flour production process involves cleaning, peeling, slicing, drying, grinding, and sieving. Nutritional composition varies among cultivars, with variations in starch, amylase, fiber, protein, and ash. The cyanogenic levels also depend on the cultivars. Cassava flour emerges as a promising wheat flour substitute due to its abundance, effortless cultivation practices, nutritional profile, and unique functional properties. Furthermore, cassava flour is gluten-free and considered as the most comparable gluten-free substitute to wheat flour in terms of texture and taste. The incorporation of cassava flour into bakery products shows an opportunity to reduce the massive

*Correspondence: madhura@sci.sjp.ac.lk

dependence on costly wheat flour imports in developing countries, which improves the country's revenues. This review focuses on diverse food applications of cassava flour, including cookies, crackers, biscuits, and commercial products, highlighting cassava flour's market potential in Sri Lanka amidst the increasing demand for gluten-free products.

Keywords: *Cassava Flour, Wheat Flour, Substitute, Sri Lanka, Food Products*

Introduction

Cassava (*Manihot esculenta*) can be considered one of the major staple foods around the globe. The United Nations Food and Agriculture Organization (FAO) states that *Manihot esculenta* holds the fourth rank as a main staple crop in developing countries, right after wheat, rice, and maize. Cassava is progressing into a major commercial and industrial trend around the globe, mostly because it can easily be adapted to flourish in varied soil conditions and climates (Mtunguja *et al.*, 2019).

As for the Sri Lankan context, this food crop was introduced to Sri Lanka during the Dutch era and currently, it acts as one of the most significant sources that fulfills the dietary requirements of Sri Lankan low-income families. Cassava is majorly grown in Sri Lanka by small and medium-scale farmers to obtain their starchy roots and it is cultivated as a large-scale open land cultivation or small-scale backyard crop. In open land, it is mostly mixed cropped with coconut and pineapple. Wet zone cassava cultivation includes Gampaha, Kegalle, Ratnapura, Colombo, and Matara Districts and the intermediate zone includes Kurunegala District. It is feasible to cultivate this on a wide scale in the arid zone that includes districts of Puttalam, Anuradhapura, Ampara, Hambantota, and Monaragala as well (Uthpala *et al.*, 2021). However, this tuber crop has a high demand in both international and local markets and Sri Lanka has an excess supply of cassava to fulfill these demands. However, in Sri Lanka, these starchy roots are mainly being consumed as boiled cassava or as fried chips and still, the potential of cassava product diversification is not fully explored by Sri Lankans.

Cassava is a cost-competitive raw tuber and has a wide availability compared to several other food crops in Sri Lanka. Processing and development can improve the economic worth of cassava rather than using it as a raw tuber (Alene *et al.*, 2018). Therefore, product diversification and value addition using cassava tubers show a promising strategy to boost demand and open doors for farmers and medium-scale business owners with limited resources to access the local and foreign markets. A large range of value-added products can be made using Cassava including alcohol, feed, biofuel, organic acids, wood layers, paper, medicines, textiles, and adhesives (Mtunguja *et al.*, 2019). In the food industry, the development of cassava into flour and starch can be used in many diversified products. Cassava flour has a great potential to partially or completely replace wheat flour in many of the bakery products in the food sector (Dini *et al.*, 2014). When compared with other root and tuber flours, it is a much better replacement for wheat flour because it contains higher starch content, simple and less costly production, and distinguishing functional characteristics (Asnawi *et al.*, 2018). There are several promising areas, such as in commercial and conventional products like pastries, biscuits, cookies or pies, breakfast cereals, cakes, noodles, breads, muffins, and doughnuts (Aristizabal Galvis *et al.*, 2017) where cassava flour could serve as a substitute for wheat flour.

In Sri Lanka, developing products from cassava flour as a replacement for wheat flour has huge potential with the current economic crisis. The UN Office for the Coordination of Humanitarian Affairs (OCHA) reports that Sri Lanka is going through its greatest economic crisis since gaining independence, which has been made worse by a significant decrease in food production as a result of poor agricultural harvests and the poorest and most vulnerable populations have been badly impacted by months of power outages, severe shortages of fuel, medications, and cooking gas, as well as inflation and increasing food costs (OCHA Regional Office for Asia and the Pacific (ROAP), 2023). This has led to significant shortages in both local and export products including wheat flour, whereas

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayawardenepura

biscuits, cookies, roti, and cakes like commercial and conventional products prices have skyrocketed due to this wheat flour shortage in Sri Lanka. (Lanka Organic Agriculture Movement (LOAM), 2022). Therefore, using cassava flour as a wheat flour substitute, to develop commercial products and conventional products will create a possible solution for the wheat flour shortage. Moreover, Cassava flour processing is relatively simple (peeling and slicing the roots, drying, grinding, and sieving to remove the unwanted particles from the final flour product) and there is no requirement of complex technology and sophisticated equipment; therefore, it can be performed in household level rurally. According to Elisabeth *et al.*, 2022, around 20.16% yield is recovered from cassava flour processing; hence, there are several business opportunities of cassava flour to be initiated by small-scale processors through processing cassava flour into numerous food products in cassava cultivation areas (Elisabeth *et al.*, 2022).

Cassava

Cassava is a long tuberous starchy root crop that belongs to the Euphorbiaceae family (Uthpala *et al.*, 2021). It has common names including manioc, yucca, tapioca, and Brazilian arrowroot (Xu *et al.*, 2020). Cassava is a perennial plant, but it is primarily grown as a yearly crop because its starchy roots have high demand. It grows well in tropical regions and shows excellent drought tolerance, allowing cultivation in environmentally stressed areas where other crops struggle to grow (Elisabeth *et al.*, 2022).

Limitations of Cassava as a Food Crop and Necessity of Processing

There are two major limitations (Figure 1) associated with cassava, which are, the presence of toxic cyanogenic glucosides and the rapid perishability of cassava (Murtuza *et al.*, 2016). These two limitations compel the processing of raw cassava to be a necessity and it will extend the shelf-life of cassava and will ensure safety for human consumption.

When considered the toxicity, cassava contains compounds that can release toxic hydrogen cyanide (HCN) when hydrolyzed, which are called cyanogenic glycosides (Rajapaksha *et al.*, 2017). Based on the cyanide content, there are two types of cassava. The first type is sweet cassava, which contains just 15-50 mg/kg of cyanide on fresh-weight basis. It is simply processed by peeling and using cooking techniques including roasting, boiling, or baking. The second type, known as bitter cassava, contains higher cyanide levels and requires more extensive processing to remove the cyanogenic content, and is not commonly used commercially (Eduardo *et al.*, 2013; Pérez *et al.*, 2018).

According to Elisabeth *et al.*, 2022, the cyanide content in processed cassava flour should be lower than 10 ppm to be considered. The cyanide levels in many cassava varieties are substantially lower than this amount. To reduce the risks connected with cyanide consumption, it is necessary to use careful treatments and cooking practices. In addition to cyanogenic glycosides, cassava also includes tannins and phytic acid as antinutrients. Because tannins are anti-thiamine factors, they decrease the absorption of thiamine (vitamin B1) and contribute to astringency in foods. Condensed tannins, on the other hand, have been said to lower the risk of coronary illnesses. Phytic acid, released from phytic acid dissociation, can reduce the absorption of iron and precipitate other vital elements like calcium, magnesium, zinc, copper, and manganese. Phytate ions, which are derived from phytic acid, show anticarcinogenic activity but can also affect mineral absorption. When measured on a dry basis, the amount of phytic acid in cassava flour ranges from 95-136 mg/100 g, and sweet potato flour contains nearly 10 times lower amount than that. Even though Cassava contains several antinutrients, however their concentrations are normally not of concern. (Montagnac *et al.*, 2009; Dini *et al.*, 2014).

The above limitation can be reduced by processing techniques, and it will extend the shelf-life of cassava and reduce post-harvest losses. Reducing these limitations, the sustainable utilization and widespread use of cassava as a food can be achieved (Pérez, *et al.*, 2018).

Cassava's perishability and the subsequent post-harvest losses are its second limitation. Due to

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura

its extreme perishability, cassava can only be kept after harvest for a limited time, often 2 to 3 days. Perishability is caused by two main factors. Those are microbiological spoilage and physiological deterioration. During harvesting and processing, mechanical injury results in physiological degradation. As a result, endogenous enzymes are released, which hydrolyze cyanogenic glycosides, which lead to the creation of toxic hydrocyanic acid, and that limits the cassava edibility. During storage, microbial deterioration during storage also contributes to post-harvest losses (Booth, 1976). This limitation can be reduced by processing techniques, and it will extend the shelf-life of cassava and reduce post-harvest losses. Reducing these limitations, the sustainable utilization and widespread use of cassava as a food can be achieved (Pérez, *et al.*, 2018).

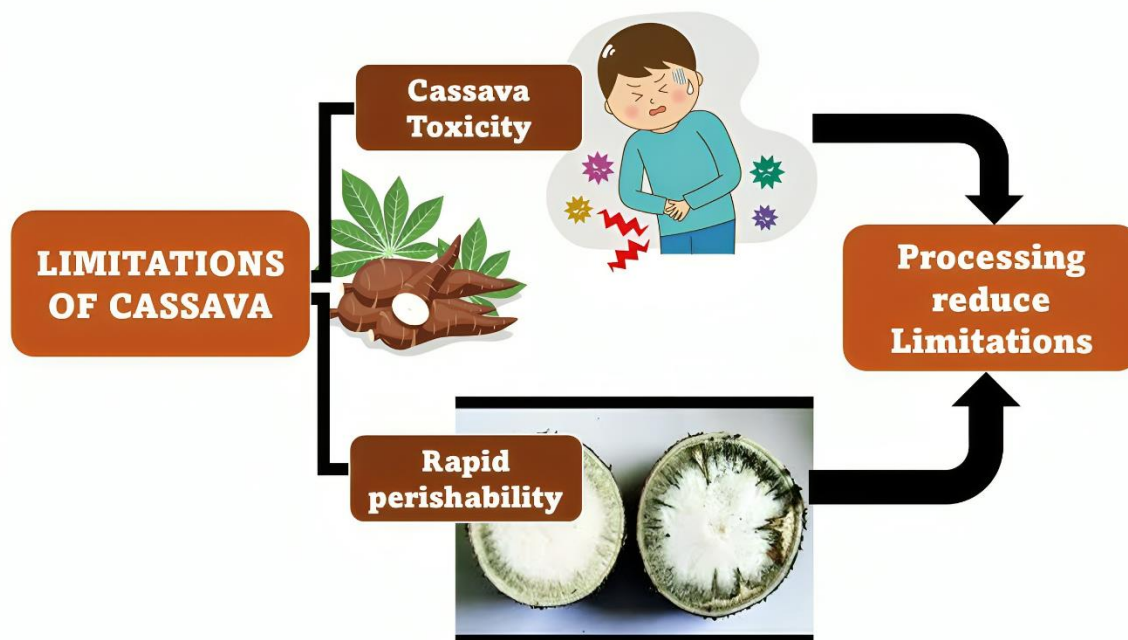


Figure 1: Limitations of Cassava

Sri Lankan Cassava Varieties, Consumption, Nutrition and Morphological Diversity

In Sri Lanka, cassava is a widely consumed root crop. Wild accession, MU51, CARI555, Kirikawadi, Shani, Swarna, Suranimala, Hordi MU1, and landrace varieties are among the cassava cultivars grown in Sri Lanka. Among them, CARI 555, MU51, and Kirikawadi are popular varieties used in food processing (Nilusha, Perera, P. I. P. Perera, *et al.*, 2019). According to M. A. D. Somendrika *et al.*, 2016, the most usual form of cassava consumption in Sri Lanka is boiled cassava. Using cassava to extract starch is also done occasionally. This starch extracted from cassava is used in a variety of industrial processes as well as human and animal sustenance. Despite its long-standing consumption, the data available on the toxicological content and the nutritional composition of cassava tubers in Sri Lanka is very limited (Dini *et al.*, 2014).

According to Rajapaksha *et al.*, (2017), the nutritional composition of MU51 flesh can be better understood by analysis. The level of water in the sample is shown by the average moisture content of 61.00 ± 0.60 . An estimate of the mineral composition is provided by the ash content, which averages at 1.37 ± 0.06 . Additionally, the average total fat content of MU51 flesh is 0.71 ± 0.18 , the average protein content is 2.09 ± 0.22 , and the average crude fiber content is 2.15 ± 0.43 . The presence of indigestible dietary fiber is shown by the crude fiber content. Lastly, the average carbohydrate content, including sugars and starches, in MU51 flesh is 32.68 ± 1.35 .

The morphological diversity of Sri Lankan cassava cultivars is seen in the features of their

*Correspondence: madhura@sci.sjp.ac.lk

leaves, stems, and tubers. Table 1 highlights the key differences and similarities in the morphological features of the Landrace, Wild-accession, Swarna, Kirikawadi, and Suranimala cassava cultivars (Dissanayake *et al.*, 2019).

Table 1: Comparison of the morphological features of selected Sri Lankan cassava cultivars

Morphological Feature	Comparison
Leaf Length	Landrace: Noticeably longer. Others: Essentially identical.
Leaf Width	Wild accession: Noticeably broader. Others: Similar.
Stem Diameter	Landrace: Narrowest. Wild-accession and Swarna: Largest. Others: Similar.
Internodal Stem Length	Landrace: Smallest. Wild-accession and Kirikawadi: Longest. Others: Similar.
Tuber Quantity	Suranimala: Greatest amount. Others: Varies greatly.

Cassava Production and Market

Globally, cassava plays a fundamental role in addressing food insecurity in the world due to its ability to withstand challenging growing conditions and deliver stable yields. Nigeria holds the position of the world's largest cassava producer, and Thailand takes the lead in cassava starch exports (Amer, 2017). However, the agricultural potential of cassava in Sri Lanka and other parts of Asia remains largely untouched, allowing further exploration and utilization (Somendrika *et al.*, 2016). People over 500 million worldwide depend on cassava as a main food source, most particularly in Africa and tropical Asia. This crop has become a vital source of carbohydrates and energy, providing a solution for regions facing food shortages (Murtuza *et al.*, 2016). Cassava offers massive agricultural potential, especially in regions with low nutrient availability and limited access to water. It can be cultivated in marginal soils and under conditions of drought, heat stress, and diverse environmental factors (Amer, 2017). Its robust nature allows for efficient small-scale production by low-income, smallholder farmers without heavy mechanization or expensive inputs. Cassava's versatility extends beyond food consumption, as it can be processed and value added into a wide range of goods including flour, cassava chips, beer, and animal feed etc. This diversification adds to its value as a cash crop, offering economic opportunities for farmers and contributing to local economies (Elisabeth *et al.*, 2022).

Cassava production in Sri Lanka has been estimated at 307,996.1 metric tons in the year 2022, with a cultivation extent of 21,090.6 hectares according to Sri Lankan Census and Statistics. (Department of Census and Statistics, 2022). There is a surplus production of cassava in the country, making it an underutilized tuber crop with high demand in both local and foreign markets (Somendrika *et al.*, 2016). However, there is a need to develop proper technologies to increase the utilization of cassava as processed foods, thus improving its potential utilization and minimizing postharvest losses (Elisabeth *et al.*, 2022). In Sri Lanka, cassava production systems involve backyard cultivation and open-land large scale cultivation in wet zones (such as Gampaha, Kegalle, Ratnapura, Colombo, and Matara districts). Additionally, mixed cropping with pineapple and coconut is common in these areas. In the intermediate zone (Kurunegala district), similar cultivation practices are followed. Large-scale chena cultivation is considered viable in the dry zone (Putlam, Ampara, Hambantota, Anuradhapura and, Moneragala districts). Peak cassava production occurs during the Maha season (Uthpala *et al.*, 2021).

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura

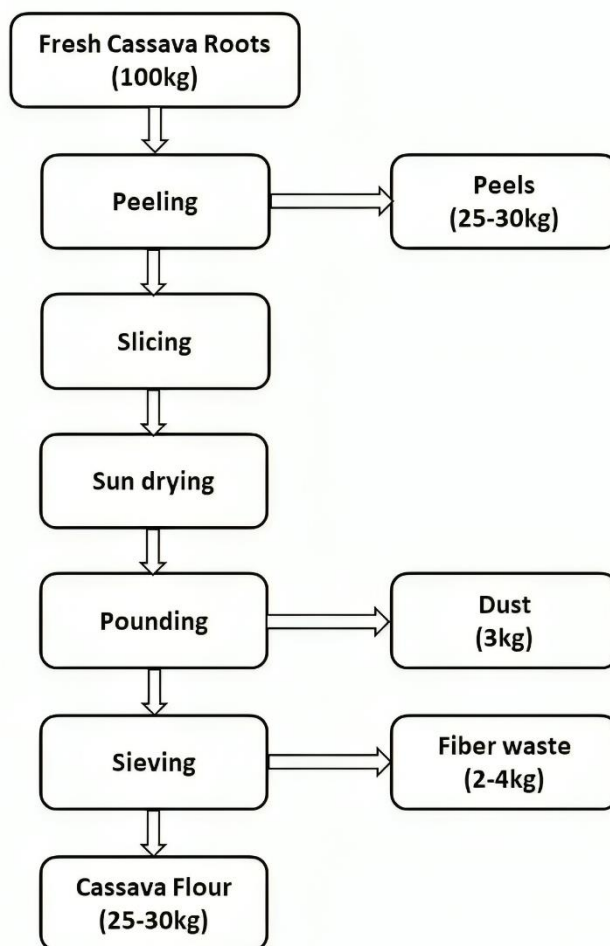


Figure 2: Cassava Flour Production Process (Uthpala *et al.*, 2021)

Cassava Flour

Edible cassava flour is derived from *Manihot esculenta*. To produce flour (Figure 2), the tubers must be cleaned and peeled to remove any damaged and unwanted parts. After that, the tubers are cut into thin pieces, dried under the sunlight or in an air convection oven, ground into a powder using a grinder, and sieved (Uthpala *et al.*, 2021). Heat is required to remove moisture content, and water is used for cleaning purposes (Somendrika and Wickramasinghe, 2015). By-products from this process can be further utilized, contributing to a sustainable cassava industry (Dini *et al.*, 2014). Approximately 30% of flour can be obtained from fresh cassava roots using this process (Uthpala *et al.*, 2021). In the case of bitter cassava, detoxifying can be done by soaking the tubers in water for a few days before drying them as whole, pounded tubers, or small pieces can detoxify them. (Pérez *et al.*, 2018).

The heap fermentation or sun drying of the peeled roots followed by pounding and sifting are two of the most followed methods of processing cassava tuber to obtain flour. These techniques are employed to ensure limited plant cell disruption and minimal contact between linamarin and linamarase enzymes. As a result, the flour's residual total cyanide concentration is less than 12–16% (Jansz and Inoka Uluwaduge, 1997). While traditional flour production involves sun drying, large-scale manufacturing utilizes artificial dryers such as rotatory, trays, fixed bed, or flash dryers. When incorporating dried flour into bread, it is recommended to do a low temperature drying at around 50

*Correspondence: madhura@sci.sjp.ac.lk

°C and it will help to maintain a light color (Uthpala *et al.*, 2021). To produce a one-kilogram yield of refined cassava flour, four kilograms of fresh cassava is needed. To transform the cassava roots into flour the moisture content should be reduced from the initial level of raw cassava to 12% using heat energy. This process involves the removal of approximately 65% of the moisture present in the cassava roots (Uthpala *et al.*, 2021).

Cassava flour is commonly used in the feed, food, and chemical industries, and its high availability and physicochemical properties make it an attractive ingredient for the food industry (Neang *et al.*, 2013). It possesses high purity, unique thickening properties, and the ability to form clear viscous pastes (Nilusha, Perera, P. P. Perera, *et al.*, 2019). In the food industry, cassava flour is processed into value additions such as pre-gelatinized instant and convenience foods including gari, pupuru, and fermented cassava flour. It is also used as a filler material and binding agent in processed baby foods, confectionery, and biscuit industries due to its bland flavor (Nilusha, Perera, P. P. Perera, *et al.*, 2019).

According to the Codex Alimentarius Committee, 1989, Edible cassava flour must meet several standards to ensure its safety and suitability for human consumption. It should be free from abnormal odors and flavors, filth, and living insects that could pose health hazards. The moisture content should not exceed 13%, although lower limits may be required based on climate and storage conditions. The hydrocyanic acid content should not exceed 10 mg/kg, and it should be free from heavy metals, pesticide residues, and mycotoxins according to Codex Alimentarius Commission limits.

Functional Properties

The functional properties of cassava flour vary among different types of Sri Lankan cultivars like Suranimala, Swarna, Shani, MU51, and Kirikawadi cultivars (Table 2). According to Nilusha *et al.*, 2019, the moisture content of the flour shows substantial differences among most cultivars, except for Kirikawadi and Suranimala cultivars. The moisture content ranged from 4.45% to 7.78%. The flour from the Swarna cultivar had the highest moisture content, while the flour from the MU51 cultivar had the lowest moisture content. Regarding ash content, the Suranimala cultivar had the highest ash content (2.06%), while the Kirikawadi cultivar had the lowest ash content. Significant differences were observed in ash content among five cultivars, except for Kirikawadi, MU51, and Shani cultivars. The oil holding capacity (OHC) and the water holding capacity (WHC) also varied among cultivars. The flour from the Kirikawadi cultivar had the highest WHC (308.25%) and the flour from the Swarna cultivar had the highest OHC (120.65%). The flour from the Suranimala cultivar had the lowest WHC and OHC. Significant differences in WHC were observed among most cultivars, except for MU51 and Shani cultivars. Similarly, significant differences in OHC were observed between Swarna, MU51 cultivars, and Suranimala cultivars. The protein fractions and hydrophobicity of the proteins contribute to the differences in WHC and OHC. The formulation of sausages, processed cheese, and bakery products can be done with high WHC flour, while high OHC is beneficial for extended shelf life, flavor retention, and palatability in meat products.

The swelling power (SP) and water solubility index (WSI) of cassava flour ranged from 6.79% to 16.43% and 1.91% to 4.64%, respectively. Significant differences in WSI were observed for Suranimala cultivar compared to Kirikawadi, MU51, Swarna, and Shani cultivars. Several insights about the interaction between starch chains are given by SP and WSI, while determining the thickening, pasting and textural, properties of starch-based productions as well. Cassava flour from above mentioned cultivars shows the possibility of various productions in the food industry.

Gelation properties, as indicated by the least gelation concentration (LGC), varied among cultivars. Kirikawadi flour formed a gel at a higher concentration (10%), while Shani flour formed a gel rapidly at a lower concentration (4%). Significant differences in LGC were observed between Shani and Suranimala cultivars, as well as between these cultivars and others. The gelation capacity, influenced by the globulin fraction, makes these proteins suitable for thickening and gelling properties

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayawardenepura

in food systems such as puddings and sauces. Gelatinization temperature (GT) ranged from 68.11°C to 68.61°C, with no significant differences among the cultivars. Higher GT can be attributed to the high amylopectin content, which hinders gel formation. Bulk density (BD) ranged from 2.28 g/ml to 2.03 g/ml. Higher BD indicates good thickening properties in food preparations. Emulsion stability (ES) and Emulsion activity (EA) varied among the cultivars, with EA ranging from 62.37% to 44.62% and ES ranging from 48.53% to 44.66%. MU51 cultivar showed significant differences in EA compared to Shani and Suranimala cultivars (Nilusha, Perera, P. I. P. Perera, et al., 2019).

Table 2: Physical and Functional characteristics of Sri Lankan Cassava Cultivars

Functional Property	Cassava Cultivar				
	Kirikawadi	MU51	Swarna	Shani	Suranimala
Moisture (%)	6.56 ± 0.29	4.45 ± 0.39	7.78 ± 0.42	5.35 ± 0.01	6.49 ± 0.03
Ash (%)	1.12 ± 0.02	1.34 ± 0.11	1.68 ± 0.04	1.23 ± 0.08	2.06 ± 0.01
WHC (%)	308.25 ± 7.23	275.18 ± 12.99	211.09 ± 8.55	261.29 ± 11.16	159.72 ± 5.61
OHC (%)	110.9 ± 0.83	98.82 ± 3.01	120.65 ± 8.55	107.53 ± 12.93	97.62 ± 5.44
WS1 (%)	2.72 ± 0.19	1.91 ± 0.25	2.17 ± 0.08	2.97 ± 0.01	4.64 ± 1.44
SP (%)	6.79 ± 0.1	16.43 ± 0.99	8.09 ± 0.42	10.80 ± 0.33	10.40 ± 0.39
LGC (%)	10	8	8	4	6
GT (°C)	68.33 ± 0.58	68.33 ± 0.58	68.00 ± 1.00	68.33 ± 0.57	68.61 ± 0.58
BD(g/ml)	2.03 ± 1.15	2.17 ± 2.89	2.08 ± 0.57	2.13 ± 2.12	2.28 ± 0.71
EA (%)	52.54 ± 0.54	62.37 ± 0.29	53.53 ± 0.01	44.62 ± 8.56	45.87 ± 2.86
ES (%)	45.96 ± 1.14	48.95 ± 0.61	46.96 ± 0.81	46.94 ± 0.54	44.66 ± 2.86

Values are expressed as "Mean ±SD" of three independent determinations.

OHC -Oil Holding Capacity, WSI -Water Solubility index, WHC - Water Holding Capacity, LGC - Least Gelation Concentration, SP -Swelling Power, , GT -Gelatinization Temperature, BD - Bulk Density, EA - Emulsion Activity, ES - Emulsion Stability (Nilusha, Perera, P. P. Perera, et al., 2019)

Nutritional Properties

When considering the nutritional composition, cassava flour mainly consists of carbohydrates, with a higher amount being starch. It contains considerably different amounts of moisture, lipid, proteins, ash, and acid detergent fiber. The composition can vary among different cassava cultivars, with variations in starch, sugar, amylase, pH, and cyanogenic levels. The flour also contains prominent amounts of several minerals including sodium, potassium, calcium, magnesium, and iron, which contribute to its mineral profile (Oyeyinka et al., 2019).

Cassava flour has been analyzed for its chemical composition, revealing various components. On a dry basis, it was found to contain 92.5±0.9% carbohydrates, with 83.5±2.5% of that being starch. The moisture content was determined to be 10.2±0.1%, while the ash content accounted for 3.45±0.04% of the flour. Lipids are contained in 0.48±0.02% of the composition, proteins contributed 3.7±0.7%, and acid detergent fiber accounted for 1.9±0.2% of the composition. These values indicate the proportions of these components in cassava flour (Dini et al., 2014). Studies by Shittu et al., 2007, have shown that different cassava cultivars present varied compositions of cassava flour. Several components like starch, sugar, amylase, and pH levels were found to differ significantly among the cultivars studied. The ash, sugar, and protein contents exhibited slight variations, ranging from 1.5% to 3.6%, 1.2% to 2.2%, and 0.8% to 1.9% (dry basis), respectively. The potential cyanide content ranged between 0 and 38 mg/kg (dry basis). The starch and amylose contents exhibited the highest

*Correspondence: madhura@sci.sjp.ac.lk

variations, ranging from 65% to 88% and 13% to 23% (dry basis), respectively. Regarding mineral content, Oboh, Akindahunsi and Oshodi, 2002, highlighted the presence of certain minerals in cassava flour. On a dry basis, it was reported to contain $43.8 \pm 0.3\%$ sodium, $61.6 \pm 0.7\%$ calcium, $49.8 \pm 0.4\%$ potassium, $43.4 \pm 0.2\%$ magnesium, and $26.0 \pm 0.4\%$ iron. These mineral contents provide insight into the presence of essential minerals in cassava flour.

In the Sri Lankan context, Rajapaksha, Somendrika and Wickramasinghe, 2017, have conducted the proximate analysis of Cassava flour extracted from MU51 cultivar. According to the results, it has a moisture content of $12.15 \pm 0.47\%$, which aligns with the Codex standard for edible cassava flour (Codex Alimentarius Committee, 1989). The relatively low moisture content indicates that most of the water has been removed during processing, resulting in a dry flour product. The ash content of cassava flour, which represents the inorganic minerals present in the sample, is measured to be $1.09 \pm 0.04\%$. This value is not significantly different from the control sample, which is MU51 flesh, indicating that the ash content remains relatively stable throughout the processing of cassava into flour. These ash quantities are in line with those reported in other studies (Montagnac, Davis and Tanumihardjo, 2009), suggesting that cassava flour retains the mineral composition of the original cassava tubers to a considerable extent. In terms of fat content, cassava flour from MU51 cultivar has a relatively low concentration, ranging from 0.66% to 0.70%. The protein content of cassava flour was $2.00 \pm 0.21\%$ which is slightly lower than MU51 flesh which has a protein content of $2.09 \pm 0.22\%$. The variation in protein content among different flour and flesh can be attributed to the specific processing techniques employed and the removal of protein-rich components during processing (Montagnac *et al.*, 2009). Cassava flour contains a moderate amount of crude fiber, with a content of $1.10 \pm 0.49\%$. The observed fiber content in cassava flour is higher than the limit of 1.5% reported in a study by Gil, J. L., Buitrago, 2002, and this suggests that cassava flour can act as a beneficial source of dietary fiber.

Carbohydrates make up the majority of cassava flour's composition, with a content of $82.98 \pm 0.14\%$. (Montagnac *et al.*, 2009). As a result, cassava flour can provide a substantial amount of energy in the form of carbohydrates. The cyanide content in cassava flour is measured to be 6.03 mg.kg^{-1} on dry basis and is lower than the cyanide content in fresh MU51 tuber. The processing steps involved in cassava flour production, including cutting, drying, and grinding, likely contribute to the reduction of cyanide levels compared to the fresh tuber (Pieris, 1974). However, it is important to note that cyanide levels should be carefully monitored during processing to ensure they remain within safe limits for consumption.

In another study done by Nilusha, Perera, P. I. P. Perera, *et al.*, 2019, different cassava cultivars were analyzed for their nutritional composition, including ash, fat, protein, and phenolic contents. According to that study, Suranimala exhibited the highest ash content of $2.06 \pm 0.01\%$, while Kirikawadi had the lowest ash content of $1.12 \pm 0.02\%$. The ash contents showed significant differences among the cultivars. In terms of fat content, Suranimala had the highest value of $0.64 \pm 0.12\%$, while MU51 had the lowest value of $0.21 \pm 0.06\%$. A significant difference in fat content was observed among the flour samples. The protein contents ranged from $1.09 \pm 0.22\%$ to $1.70 \pm 0.03\%$, with significant differences between the cultivars. The total phenolic contents, determined using the Folin Ciocalteu method, ranged from 2.69 ± 0.21 to 4.45 ± 0.08 (mmol GAE/100 dry weight), and significant differences were observed among the cultivars. These results show the changes in the nutritional composition among cassava cultivars and give essential information for their potential use as raw materials in the food industry. However, despite the long-standing consumption of cassava tubers in Sri Lanka, there is a lack of comprehensive data regarding their nutritional composition and toxicological content according to different cassava cultivars (Rajapaksha, *et al.*, 2017).

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura

Comparison with Wheat flour

Wheat (*Triticum aestivum*) is a widely consumed staple food by a large number of the world's population. When considering the nutritional composition of wheat flour, it contains approximately 11.13% moisture, 12.33% protein, 8% fiber, 1.87% fat, and 2.09% minerals (Mahendran *et al.*, 2018). Another study done by Adekunle and Mary, 2014, reported slightly different values, with moisture, 7.80%, fat, 1.27%, ash, 3.49%, fiber, 0.35%, and carbohydrate, 80.3%. The phytate content of wheat flour was measured to be 0.52%. Wheat flour is an ideal ingredient in many types of food products, mostly bakery and confectionery. Its suitability for these applications is due to its gluten content, which provides desirable texture and structure (Damaris Chinwendu *et al.*, 2017). However, there are significant challenges linked with the usage of wheat which are gluten-related allergies and scarcity of wheat in certain regions. (Eduardo *et al.*, 2013).

To ensure successful substitution of cassava flour in wheat flour products, it is crucial to understand the functional and physicochemical properties of cassava flour (Table 3). This includes evaluating its behavior in food systems, for example, gelatinization, viscosity, and texture, as well as assessing its quality standards in terms of microbial safety, physicochemical characteristics, and cyanogenic glucoside content (Elisabeth *et al.*, 2022).

Table 3: Comparison of wheat flour and Cassava flour

Feature	Wheat Flour	Cassava Flour
Gluten Content	Contains gluten (Chakrabarti <i>et al.</i> , 2017)	Gluten-free (Dini <i>et al.</i> , 2014)
Nutritional Characteristics	Protein-rich, Contains starch, ash, and lipids (Chakrabarti <i>et al.</i> , 2017)	Rich in dietary fiber, ash, lipids, and starch. Lesser protein content than Wheat flour (Oyeyinka <i>et al.</i> , 2019)
Usage in Baking	Provides unique properties due to gluten (Chakrabarti <i>et al.</i> , 2017)	A potential substitute for wheat flour in baking, but needs further understanding of its behavior in food systems (Elisabeth <i>et al.</i> , 2022)
Economic Impact (in Sri Lanka)	High import costs, strain on foreign exchange reserves (Elisabeth <i>et al.</i> , 2022)	Reduces dependency on wheat imports, cost-effective for local economies (Elisabeth <i>et al.</i> , 2022)
Cultivation Feasibility	Unsuitable climatic conditions in Sri Lanka (Dini <i>et al.</i> , 2014)	Thrives in diverse climates, a staple crop in Sri Lanka (Dissanayake <i>et al.</i> , 2019)
Health Aspects	Contains gluten, not suitable for gluten-sensitive individuals (Chakrabarti <i>et al.</i> , 2017)	Gluten-free, appealing for dietary restrictions and health-conscious consumers (Dini <i>et al.</i> , 2014)
Technological Feasibility	Well-established in baking technology (Li <i>et al.</i> , 2023)	Potential for baked goods (e.g., cookies, pastries, bread), requires evaluation of properties like gelatinization, viscosity, texture, microbial safety, and cyanogenic glucoside content (Amer, 2017; Elisabeth <i>et al.</i> , 2022)
Toxicity	Generally, do not contain any toxic compounds (Li <i>et al.</i> , 2023)	Contains cyanogenic glucosides (the amount varies with each cultivar) which can be toxic if not properly processed (Elisabeth <i>et al.</i> , 2022)

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayawardenepura

Cassava Flour Product Developments

Cassava flour has gained attention as a potential wheat flour replacement due to its gluten-free nature and unique functional properties (Kartikasari *et al.*, 2021). Several research and development efforts have been focused on utilizing cassava flour as an ingredient in various food products. With the developing interest for gluten-free food products and the increasing prevalence of celiac disease, the market potential and opportunities for cassava flour as a wheat flour substitute have also been considered. (Grand view research, 2020).

Cassava Flour as a Gluten-Free Ingredient

Cassava flour offers benefits for individuals with celiac disease, an autoimmune condition initiated by gluten consumption. Being naturally gluten-free, cassava flour gives a chance to incorporate gluten-free alternatives into the diets of celiac disease patients. The addition of cassava flour in gluten-free formulations aims to mimic the desirable properties of wheat dough, and thereby in to food products (Dini *et al.*, 2014).

Studies done by Onyango *et al.*, 2011, have focused on improving the functional properties of cassava flour-based gluten-free batters and dough. Native cassava starch and pregelatinized cassava starch have been investigated to enhance their fluidity and dough-like consistencies, respectively. Additives like hydrocolloids and emulsifiers have been explored to simulate gluten dough and enhance the overall quality of gluten-free products (Crockett *et al.*, 2012). Protein isolates and enzymes have also been examined as possible solutions to mimic the protein network found in gluten (Crockett *et al.*, 2011).

Cassava flour has shown promising development in the production of various baked goods, including cookies, pastries, cakes, breads, biscuits, and doughnuts. Modified cassava flour, achieved through thermal and enzymatic treatments, has been recommended for gluten-free food production. Additionally, the incorporation of cassava bagasse as an ingredient in gluten-free pasta not only provides comparable quality attributes but also increases fiber content, addressing both health and sustainability concerns (Dini *et al.*, 2014). Extensive research has been conducted on gluten-free cookies and cakes, with a limited focus on biscuits, muffins, and crackers. Studies into the functionality of gluten-free flours, additives, and composite flours are ongoing and need more attention in future research. The development of gluten-free alternatives that mimic the functions of wheat flour remains a challenge (Xu *et al.*, 2020).

The global gluten-free food market has experienced significant growth, creating a favorable environment for cassava flour products. With an estimated market size of \$6.7 billion in 2022 and a projected revenue of \$13.7 billion by 2030, the gluten-free bakery products segment holds the largest share. Currently, North America rules the market, but the Asia Pacific region is expected to record the highest compound annual growth rate (CAGR) of 12.1% from 2022 to 2030. This presents an opportunity for cassava flour-based products to meet the increasing demand for gluten-free alternatives (Grand view research, 2020). Ongoing research aims to improve the functional properties and replicate the characteristics of gluten in gluten-free formulations. Since there is a growing market for gluten-free products and the rising prevalence of celiac disease, there is a promising future for cassava flour-based products (Dini *et al.*, 2014). Leveraging its unique functional properties, low production cost, and relative ease of processing, cassava flour can be utilized to cater to the needs of gluten-intolerant consumers and offer viable alternatives in the global food industry.

Cassava flour as a potential ingredient in the Food Industry

The versatile nature of cassava flour opens doors for innovative food products such as gluten-free cookies, protein-enriched biscuits, energy-packed crackers, expanded snacks, pasta, chapatti, mahamri, and various extruded products, showcasing its potential in the food industry. In the development of Cassava flour cookies, Neang *et al.*, 2013 researched to optimize the temperature

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayawardenepura

and proportion of cassava flour in cookie production. They recommended a cookie recipe with 50% cassava flour baked at 170 °C for 8 minutes. This shows the potential of cassava flour as an ingredient in cookie production. The study by Adekunle and Mary, 2014, concludes that the partial substitutions of wheat flour with cassava and cowpea flours resulted in protein-enriched cookies comparable to whole wheat cookies in acceptability. Supplementing with cowpea flour increased the protein content, which balances the reduction caused by cassava flour substitution. Therefore, using both cassava flour and cowpea flour can improve cassava cookie nutrition. Bean-cassava-wheat mix flours were used by Cabal G. *et al.*, 2014, to develop a formulation for cookies to enhance the nutritional content of cookies. This formulation showed higher iron (Fe) content compared to wheat flour-based cookies. The mix flours also exhibited potential for use in the bread-making industry as substitutes for cereal-based flours, providing higher nutritional quality.

Murtuza *et al.*, 2016 studied the development of cassava crackers using cassava flour and cassava starch. The crackers were found to be an excellent source of energy and generally accepted by sensory evaluation. The cassava crackers with prawn powder study was conducted by Akonor *et al.*, 2017 and found that consumer acceptance of crackers made from high-quality cassava flour (HQCF), prawn powder (PP), and starch was generally positive. Sensory attributes were influenced by the proportion of HQCF, prawn powder, and starch. A formulation with 55% HQCF, 5% PP, and 40% starch was acceptable to the sensory panel.

A study by Nilugin *et al.*, 2015, states that incorporating mango flour into cassava flour biscuits can enhance their quality. In their study, the addition of mango flour has increased protein, ash, fiber, and vitamin C content. The 20% mango flour-supplemented biscuits were favored by the panelists and offered a cost-effective alternative to using imported wheat flour.

In cassava flour short biscuits developed by Lu *et al.*, 2020, it was found that by addition of xanthan gum to the biscuit formula improved the properties and the quality of those short biscuits. The biscuits made with an optimal cassava flour formula, including xanthan gum as a gluten substitute, were accepted and they had volatile components that are similar to low-gluten wheat flour biscuits. These gluten-free cassava flour biscuits offer a potential alternative for individuals with celiac disease. As for conventional products, Katama *et al.*, 2010, studied cassava flour in chapatti and mahamri. According to them, cassava flour has the potential to substitute up to 50% of wheat flour in chapatti and mahamri without affecting product acceptability. Modified preparation methods can further enhance the acceptability of cassava-based products. They recommend that the spreading of the usage of cassava flour can make a good contribution and impact on food security and poverty reduction in the world. Moreover, cassava flour has been used to produce a variety of extruded products, including expanded snacks and pasta. These products offer dietary value, being oil-free and gluten-free. Cassava flour presents opportunities for diverse food applications (Uthpala *et al.*, 2021). These research findings highlight the diverse potential of cassava flour in various food products, including cookies, crackers, biscuits, and related commercial and conventional products.

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura



Figure 2: Potential Cassava Flour Products Examples

Conclusions

Cassava flour derived from *Manihot esculenta* tubers has versatility, nutritional characteristics, and functional properties to position it as a promising alternative for wheat flour in various food applications. Sri Lanka, with excess cassava cultivation that exceeds local demand, promotes its use in place of imported wheat flour. This creates high potential for development and utilization in diverse food products, ranging from traditional foods to modern bakery items. Thus, cassava flour emerges as a viable alternative to gluten-free products globally and presents a sustainable and economically valuable solution for the food industry.

References

- Adekunle, O. A. and Mary, A. A., 2014, Evaluation of cookies produced from blends of wheat, cassava and cowpea flours, *International Journal of Food Studies*, 3(2), 175–185.
- Akonor, P.T., Dziedzoave, N.T., Tomlins, K.I., 2017. Sensory optimization of crackers developed from high-quality cassava flour, starch, and prawn powder. *Food Science and Nutrition* 5, 564–569.
- Alene, A.D., Abdoulaye, T., Becerra, L.A., 2018. Identifying crop research priorities based on

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura

- potential economic and poverty reduction impacts: The case of cassava in Africa, Asia, and Latin America. PLoS ONE 13.
- Amer, P., 2017. Save and Grow. Nature Middle East. doi:10.1038/nmiddleeast.2017.28
- Aristizabal Galvis, J. A., García Agredo, J. A. and Ospina Patiño, B. 2017. Refined cassava flour in bread making: a review, Ingeniería e Investigación, 37(1), p. 25.
- Booth, R. H., 1976. 'Storage of Fresh Cassava (*Manihot esculenta*). I. Post-Harvest Deterioration and its Control', Experimental Agriculture, 12(2), 103–111.
- Cabal G., D.C., Melo R., A., Tofiño R., A., 2014. Highly nutritional cookies based on a novel bean_cassava-wheat flour mix formulation, Agronomia Colombiana, 32(3), 407–416.
- Chakrabarti, T., Poonia, A. and Chauhan, A. K., 2017. Process Optimization of Gluten Free Cookies using Cassava Flour, International Journal of Food Science and Nutrition, 2(5), 190–195.
- Codex Alimentarius Committee (1989) Codex Standard for Edible Cassava Flour, Codex Alimentarius Commission FAO/OMS.
http://siweb1.dss.go.th/standard/Fulltext/codex/CXS_176E.pdf. Accessed 26 January 2024
- Crockett, R., I, P. and Vodovotz, Y., 2011^a. Effects of soy protein isolate and egg white solids on the physicochemical properties of gluten-free bread, Food Chemistry, 129(1), 84–91.
- Crockett, R., I, P. and Vodovotz, Y., 2011^b. How Do Xanthan and Hydroxypropyl Methylcellulose Individually Affect the Physicochemical Properties in a Model Gluten-Free Dough?, Journal of Food Science, 76(3), E274–E282.
- Damaris Chinwendu, O., Nkiru Odimegwu, E. and Alagbaoso, S., 2017. Production and Evaluation of Cookies from Whole Wheat and Date Palm Fruit Pulp as Sugar Substitute Evaluation of Synsepalum dulcificum (Miracle fruit) Berry View project Biodiversity Conservation View project, Researchgate.Net, 04(04), 1–31.
- Department of Census and Statistics, S. L., 2022. Highland Crops.
http://www.statistics.gov.lk/HIES/HIES2006_07Website/index.html. Accessed: 12 December 2023.
- Dini, C., Doporto, M.C., García, M.A., 2014. Cassava flour and starch as differentiated ingredients for gluten free products in Cassava: Production, Nutritional Properties and Health Effects. Nova Science Publishers, Inc., pp. 87–114.
- Dissanayake, U.H.K., 2019. Characterization of cassava (*Manihot esculenta* Crantz) cultivars in Sri Lanka using morphological, molecular and organoleptic parameters. Tropical Agricultural Research 30, 51.
- Eduardo, M., Svanberg, U., Ahrné, L., 2013. Effect of cassava flour characteristics on properties of cassava-wheat-maize composite bread types. International Journal of Food Science 2013.
- Elisabeth, D.A.A., 2022. Cassava flour production by small-scale processors, its quality and economic feasibility. Food Science and Technology (Brazil) 42.
- Gil, J. L., Buitrago, A. J. A., 2002. La yuca en la alimentacion animal, CentroInternacional de Agricultura Tropical, pp. 527–569.
- Grand view research, 2020. Gluten-Free Products Market Size, Share & Trends Analysis Report By Product (Bakery Products, Dairy/Dairy Alternatives), By Distribution Channel. <https://www.grandviewresearch.com/industry-analysis/gluten-free-products-market>. Accessed 18 November 2023
- Jansz, E.R., Inoka Uluwaduge, D., 1997. Biochemical aspects of cassava (*Manihot esculenta* crantz) with special emphasis on cyanogenic glucosides - A review. Journal of the National Science Council of Sri Lanka 25, 1–24.
- Kartikasari, S. N., Leseni, N. K. and Ida, N. C., 2021. Improve the texture of white bread from cassava flour (gluten free), IOP Conference Series: Earth and Environmental Science, 759(1).
- Katama, C.K., R.W., Muinga, Saha H. M., Gethi J., 2010). The effect of substituting wheat with cassava flour on acceptability of chapatti and mahamri in coastal Kenya, 12th KARI Biennial

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura

- Scientific Conference, 8-12.
- Lanka Organic Agriculture Movement (LOAM), 2022. Report on Background, Development and Current Food Crisis in Sri Lanka, pp. 1-7.
- Li, M. et al., (2023). Assessment of Functional Properties of Wheat–Cassava Composite Flour, *Foods*, 12(19), 1–15.
- Lu H, Guo L, Zhang L, et al., 2020. Study on quality characteristics of cassava flour and cassava flour short biscuits. *Food Sci Nutr.* 8, 521–533.
- Mahendran, T., Hariharan, G., 2018. Optimization of Wheat-Sorghum Composite Flour for the Production and Enhanced Storability of Leavened Flat Bread Naan', *Tropical Agricultural Research and Extension*, 21, p. 1,2.
- Montagnac, J. A., Davis, C. R. and Tanumihardjo, S. A., 2009. Nutritional Value of Cassava for Use as a Staple Food and Recent Advances for Improvement, *Comprehensive Reviews in Food Science and Food Safety*, 8(3), 181–194.
- Mtunguja, M.K., Beckles, D.M., Sinha, N.J., 2019. Opportunities to commercialize cassava production for poverty alleviation and improved food security in Tanzania. *African Journal of Food, Agriculture, Nutrition and Development* 19, 13928–13946.
- Murtuza, K. et al., 2016. Processing and Quality Evaluation of Crackers from Cassava Flour, *International Research Journal of Biological Sciences*, 5. 22-25.
- Neang, S. et al., 2013. Analysis of Requisite Quality of Cassava and Temperature for Baking Cookies, *IJERD-International Journal of Environmental and Rural Development*, pp 4–6.
- Nilugin, S., Mahendran, T. and Inthujaa, Y., 2015. Added Cassava-Mango Composite Flour Biscuits, *Tropical Agricultural Research & Extension*, 18(2).
- Nilusha, R. A. T., Perera, O., Perera, P. I. P., et al., 2019. Characterization of Flour from Sri Lankan Cassava (*Manihot esculenta*) Cultivars', 08, pp 100.
- Nilusha, R. A. T., Perera, O., Perera, P. P., et al., 2019. Functional Properties of Flour from Five Different Sri Lankan Cassava (*Manihot esculenta*) Cultivars, [http://dr.lib.sjp.ac.lk/bitstream/handle/123456789/12126/Functional_properties_of_flour_from_five_different_sri_lankan_cassava_\(Manihot_esculenta\)_cultivars.pdf?sequence=1](http://dr.lib.sjp.ac.lk/bitstream/handle/123456789/12126/Functional_properties_of_flour_from_five_different_sri_lankan_cassava_(Manihot_esculenta)_cultivars.pdf?sequence=1). Accessed 10 November 2023
- Oboh, G., Akindahunsi, A. A. and Oshodi, A. A., 2002). Nutrient and Anti-nutrient Contents of *Aspergillus niger* -Fermented Cassava Products (Flour and Gari), *Journal of Food Composition and Analysis*, 15(5), 617–622.
- OCHA Regional Office for Asia and the Pacific (ROAP), 2023. Sri Lanka Multi-Dimensional Crisis Situation Report. <https://www.unocha.org/publications/report/sri-lanka/sri-lanka-multi-dimensional-crisis-situation-report-no-11-17-january-2023>. Accessed 23 October 2023
- Onyango, Calvin & Mutungi, Christopher & Unbehend, G. & L.. 2011. Rheological and textural of sorghum-based formulations modified with variable amounts of native or pregelatinized cassava starch, *Lebensmittel-Wissenschaft und-Technologie*, 44, 687–693.
- Oyeyinka, S. A. et al., 2019. Physicochemical properties of flour and starch from two cassava varieties, *Agrosearch*, 19(1), p. 28.
- Pérez, Elevina & Sívoli, Lilliam & Davdmary, Cueto & Pérez, L., 2017. Cassava flour as an alternative to produce gluten-free baked goods and pastas, *Handbook on Cassava*, pp. 87-104
- Rajapaksha, K. D. S. C. N., Somendrika, M. A. D. and Wickramasinghe, I., 2017. Nutritional and toxicological composition analysis of selected cassava processed products, *Potravinarstvo Slovak Journal of Food Sciences*, 11(1), pp. 35–42.
- Sciari, L.S., Ribotta, P.D., León, A.E., (2012) 'Incorporation of several additives into gluten free breads: Effect on dough properties and bread quality', *Journal of Food Engineering*, 111(4), 590–597.
- Shittu, T. et al., 2007. Use of multivariate techniques in studying the flour making properties of some

*Correspondence: madhura@sci.sjp.ac.lk

© University of Sri Jayewardenepura

- CMD resistant cassava clones, *Food Chemistry*, 101(4), pp. 1606–1615.
- Somendrika et al., 2016. Quantification of the Material Flow of Raw Cassava Tubers Processing for Export Market, *European Journal of Academic Essays*, pp. 105–108.
- Somendrika, D. and Wickramasinghe, I., 2015. Quantification and Chemical Analysis of Waste Generated during the Processing of Cassava Crocket Quantification and Chemical Analysis of Waste Generated during the Processing of Cassava Crocket, pp. 2–3.
- Somendrika, M. A. D. et al., 2016. Analyzing Proximate Composition of Macro Nutrients of Sri Lankan Cassava Variety “Kirikawadi”, *Pakistan Journal of Nutrition*, 15(3), pp. 283–287.
- Uthpala, T. G. G. et al., 2021. Cassava: A Potential Food Source for Value-added Product Developments in Sri Lanka, *Advances in Agricultural and Life Sciences*, (7), 57–78.
- Wylis Arief, R., Novitasari, E., and Asnawi, R., 2018. Food Diversification of Cassava as Functional Food Instead of Rice in Lampung, *Planta Tropika: Journal of Agro Science*, 6(2).
- Xu, J. et al., 2020. Advanced properties of gluten-free cookies, cakes, and crackers: A review, *Trends in Food Science and Technology*, 103(April), 200–213.

*Correspondence: madhura@sci.sjp.ac.lk