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ORIGINAL RESEARCH PAPER

SWEET POTATO STARCH-BASED TAPIOCA GRITS: INFLUENCE OF MORINGA SEED FLOUR INCLUSION ON THE FUNCTIONAL, RHEOLOGICAL, AND SENSORY QUALITIES OF THE GRUEL

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Abstract
This study aimed to evaluate the influence of moringa seed flour (MSF) inclusion on the functional and rheological properties of sweet potato starch (SPS)-based tapioca grits and the sensory acceptability of the gruel. The MSF (2-10%) was properly blended with the SPS (90-98%), using the Central Composite Rotatable Design of the Design-Expert Software. Each blend of the SPS and the MSF, 100%SPS, and cassava starch (CS) were separately toasted at 120 -150oC for 20 min. The grits' functional and pasting properties and the gruel's sensory acceptability were determined using standard methods. The results depict that the MSF inclusion increased the bulk density (80.00 to 83.00%) and oil absorption capacity (70.00 – 81.50%), while the water absorption capacity (518.50 – 108.50%), solubility index (14.00 – 2.00%), and swelling power (13.75-5.58%) decreased. Also, the SPS-MSF tapioca grit’s peak (332.88 – 426.17 RVU), trough (162.04 – 302.71 RVU), final (228.08 – 456.59 RVU), and setback (66.04 – 153.88 RVU) viscosities, peak time (4.34 – 5.90 min) and pasting temperature (57.40 – 82.40oC) increased with MSF inclusion, and the breakdown viscosity (170.84- 52.79 RVU) decreased. Although all the sensory attributes of the SPS-MSF tapioca gruel fall within the likeness range, tapioca gruel produced from 98 g SPS and 10 g MSF blends (7.91) was very much liked compared to the CS tapioca gruel (7.09) in terms of the overall acceptability. Therefore, adding MSF to the SPS-based tapioca grits influences most of the cooked gruel's rheological properties and sensory acceptability.

Keywords: sweet potato starch, tapioca, moringa seed flour, functional properties, rheological properties, sensory acceptability

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Introduction

Millions of people in developing countries consume sweet potatoes, making them an essential food security crop. Sweet potatoes are a food product that provides calories, dietary fiber, proteins, vitamin C, and iron. Sweet potatoes' dry matter is around 80–90% carbohydrates, primarily starch and sugar with smaller amounts of pectin, hemicelluloses, and cellulose (Waidyarathna and Ekanayake, 2021). Most businesses and governments now strongly emphasize focusing on the whole value chain of sweet potatoes, from production to markets. According to a study of Oke and Workneh (2013) on sweet potato output in poor nations, value addition is an important postharvest requirement. Additionally, Pravakar *et al.* (2010) proposed that adding value to agricultural goods is a way to commercialize them, boost farmers' revenue, and therefore lessen rural poverty and food insecurity.

According to Bergh *et al.* (2012), the majority of the farmers in the Kwara State of Nigeria add value to their sweet potato tubers by typically peeling and boiling, roasting, and frying them into chips or peeled, sun-dried, and milled into flour. According to Adeyonu *et al.* (2016), there isn't much commercial processing of sweet potatoes into flour or chips, which may be preserved for year-round usage in cooked dough, bread, and cakes, or turned into fermented and dried products, such as *fufu*. According to Ray and Tomlins (2010), sweet potato tuber flour can be used to enrich a number of other products, including weaning foods, or combined with wheat flour to create additional high-value products, such as cakes, biscuits, porridge, chin-chin, and other food products. However, there is currently little knowledge of the usage of sweet potato starch in the production of tapioca, specifically in Kwara State, Nigeria.

According to Eke *et al.* (2010), tapioca is a partially-gelatinized form of roasted cassava starch that looks like grits or irregularly shaped granules. The resulting tapioca grits are often blended with milk and chopped coconut and softened with hot water before consumption, acting as a channel for various crucial nutrients for improved eating quality and protein supplements (Akintayo *et al.*, 2019). People of various ages and socioeconomic groups often consume tapioca meals, especially as breakfast. According to studies, using new ingredients in place of those that have been traditionally used in food can increase the use of less-expensive ingredients, and improve nutritional status (Balogun *et al.*, 2012; Oluwamukomi and Jolayemi, 2012; Otegbayo *et al.*, 2013), and have positive health effects (Ojo and Akande, 2013). The only known raw material for the production of tapioca grits is cassava (*Manihot esculenta* Crantz) starch, even though there are many other roots and tubers, such as sweet potato, which are also locally available in the tropics.

It is feasible to produce tapioca from sweet potato tubers in the same way it has been originally produced from cassava roots. Sweet potatoes tubers and cassava roots are traditional staples that are particularly appealing to low-income people, due to their nutritive and caloric values and contribution to livelihood systems. The two crops are also adaptable to a wide range of growing conditions and low susceptibility to drought (Pathleen and Janet, 2015). However, products made from roots and tubers are lacking in protein, micronutrients, and macronutrients. For this reason, it is necessary to include a source of protein, micronutrients, and macronutrients that is easily accessible, such as flour made from moringa seeds.

Moringa (*Moringa oleifera* Lam.) seeds can be eaten raw or cooked and when fried, they have a peanut-like flavour. The oil from the seed is similar to the olive oil and is high in oleic, palmitic, stearic, and behenic acids (Leone *et al.*, 2016). Moringa seeds are reported to be a good source of protein, vitamins, minerals, essential amino acids, phytochemicals, and antioxidants (Leone *et al.*, 2016). Some of the nutritional deficiencies of sweet potatoes may be remedied by adding moringa seeds, which may also affect the rheological properties of the tapioca grits and the gruel's sensory acceptability. Therefore, this study was conducted to assess the effects of adding moringa seed flour on the functional and rheological properties of tapioca grits, as well as the gruel's sensory acceptability in Kwara State, Nigeria.

Materials and methods

Materials

Fresh sweet potato tubers, fresh cassava roots, and *Moringa oliefera* seeds were purchased from Owode Market, Offa, Kwara State, Nigeria.

Production of cassava starch

The cassava roots (20 kg) were peeled using a knife, then washed with clean water and grated using a grating machine. The resulting cassava mash was then mixed with water in a ratio of 1:10 and sieved through a muslin cloth. The sieved mixture was allowed to rest for 2 h to help the sedimentation process of starch and the liquid at the top was decanted and discarded. The starch residue was then washed several times with clean water to obtain a white, odourless starch. The starch was partially drained before being used for the production of tapioca (Awoyale *et al.,* 2019).

Production of sweet potato starch

Wholesome sweet potato roots (20 kg) were peeled using a knife, then washed with clean water, and grated using a grating machine. The resulting sweet potato mash was then mixed with water in a ratio of 1:10, and sieved through a muslin cloth. The supernatant was then decanted within a day, and the starch residue was then washed several times with clean water to obtain a white, bland starch. The starch was partially drained prior to further processing into tapioca (Awoyale *et al.,* 2019).

Production of Moringa oliefera seed flour

After being sorted to remove spoiled, rotten, and contaminated materials, moringa seeds were dehulled to remove the seed coat, which was followed by 48 h of oven-drying at 50°C. The dried seeds were then ground into flour using an attrition mill and finally sieved to obtain fine flour (Oluwole *et al.,* 2013).

Production of tapioca grits

The moringa seeds flour was adequately blended (using a stainless-steel blender) with the partially dewatered sweet potato starch (40% moisture content). The blending ratios were determined using the Central Composite Rotatable Design of the Design-Expert (Version 7.0), with the sweet potato starch ranging from 90-98%, and the moringa seeds flour 2-10% (Table 1). Then, using a stainless-steel pan and stirrer, each blend of sweet potato starch and moringa seeds flour was separately toasted on a hot gas cooker at 120-150°C for 20 min. Squeezing the finished tapioca on the palm to check for dryness signaled the conclusion of the roasting process. The tapioca was spread out on a tray to cool after roasting, and a sample was taken to the laboratory for analysis (Adeboye *et al.*, 2019).

Table 1. Blends of sweet potato starch and moringa seed flour.

Runs	Sweet potato starch (g)	Moringa seed flour (g)
1	94.00	6.00
2	98.00	10.00
3	90.00	2.00
4	99.66	6.00
5	88.34	6.00
6	94.00	6.00
7	90.00	10.00
8	94.00	6.00
9	94.00	0.34
10	98.00	2.00
11	94.00	6.00
12	94.00	11.66
13	94.00	6.00

Functional properties of tapioca grits

Bulk density

An amount of 50 g of tapioca grit sample was placed in a 100 mL measuring cylinder. The cylinder was then repeatedly tapped on a stable surface (table) until the desired volume was achieved. The bulk density (BD) (g/cm^3) was calculated by dividing the sample's weight (g) by its volume (cm^3) (Awolu, 2017).

Water and oil absorption capacities

The samples' water (WAC) and oil (OAC) absorption capacities were measured, with some slight modifications in accordance with procedures reported by Awolu (2017). In a centrifuge tube, one gram of the sample was combined with 10 mL of either distilled water for the WAC or oil for the OAC. On a Griffin flask shaker, the suspension was stirred for an hour before being centrifuged for 15 min at 2200 rpm. The volume of water or oil in the sediment was measured. According to the amount of water or oil absorbed per gram of the sample, the WAC and OAC were computed.

Swelling power and solubility index

The samples' swelling power (SWP) and solubility index (SI) were determined using the method described by Afoakwa *et al.* (2012). About 2.5% of an aqueous starch dispersion was placed in centrifuge tubes, covered to avoid leaks, and heated for 30 min in a water bath (Precision Scientific Model 25 shaker) at 85°C. After heating for 15 min at 3,000 rpm with a centrifuge (Thelco GLC-1, 60647: Chicago, USA), the tubes were allowed to cool to ambient temperature. The paste and supernatant were separated, then the paste was weighed. At a temperature of 105°C, the liquid above the sediment was evaporated in a hot air oven (Memmert GmbH+Co.KG, Germany), and the residue was weighed. The SWP and SI were calculated using equations 1 and 2, respectively.

$$SWP = \frac{\text{Weight of starch paste}}{\text{Weight of dry starch sample}} \quad (1)$$

$$SI = \frac{\text{Weight of solubles}}{\text{Weight of sample}} \times 100 \quad (2)$$

Pasting properties

A Rapid Visco Analyser (RVA) (Model RVA 4500, Perten Instrument, Australia) equipped with a 1000 cmg sensitivity cartridge was used to measure the samples' pasting properties. A dried, empty canister was filled with 25 mL of distilled water and 3.5 g of the samples. After properly stirring the mixture, the canister was inserted into the RVA. The slurry was heated at a rate of 1.5°C/min from 50 to 95°C, maintained for 15 min, and then cooled to 50°C. Peak, trough, breakdown, final, and setback viscosities, peak time, and pasting temperature were the attributes of the viscosity profile that was obtained from the pasting profile using Thermocline for Windows Software connected to a computer (Donaldben *et al.*, 2020).

Sensory properties

Five hundred gram of each sample of tapioca grits was soaked in 1 liter of water for 7 hours to make gruel. For each sample, 1 liter of water was boiled to 100°C inside a stainless-steel pot. The sample was then added, and the mixture was continuously stirred for 10 min to get the desired consistency. Ten trained panelists were chosen from Kwara State University students in Malete, Kwara State, and tested for interest in and ability to differentiate between food sensory qualities of tapioca gruel as reported by Awoyale *et al.* (2019). Some of the sensory qualities evaluated by the panelists were appearance, taste, mouthfeel, texture, and colour recognition. The panelists were given samples that were coded and asked to compare the sensory attributes of the SPS-MSF tapioca gruel to that of cassava starch using a 9-point hedonic scale, where 9 equals extremely like and 1 equals extremely dislike. The principles of the 1964 Declaration of Helsinki, were adhered to throughout this study's sensory evaluation. Participants gave informed consent via the statement "I am aware that my responses are confidential, and I agree to participate in this study". The participants were able to withdraw from the study at any time without giving a reason.

Statistical analysis

The analysis of variance (ANOVA) of the data generated was performed using the Statistical Package for Social Scientists (SPSS version 21).

Results and discussion

Functional properties of tapioca grits

According to Awoyale *et al.* (2019), functional properties reveal how the food materials under evaluation would interact with other food components, either directly or indirectly, influencing processing applications, food quality, and final acceptability. The functional properties of tapioca grits made from cassava starch (CS), sweet potato starch (SPS), and sweet potato starch-moringa seed flour (SPS-MSF) are shown in Table 2. The tapioca grits' average functional properties, as shown by the findings, are as follows: BD 74.40%, WAC 230.43%, OAC 70.67%, SI 6.79% and SWP 10.36%. Significant differences ($p<0.05$) existed in every one of the functional properties (BD, WAC, OAC, SI, and SWP) of the tapioca grits, however with no significant difference ($p>0.05$) among CS and SPS tapioca grits in terms of the BD, OAC, and SI (Table 2).

According to Oppong *et al.* (2015), the BD plays an essential role in assessing foods in terms of their weight, handling requirements, and the type of packaging materials appropriate for storing and transporting food products. Although there was no statistically significant difference between the BD of the SPS and CS tapioca grits ($p>0.05$), the CS's BD (83%) was higher than the SPS's (80%). The BD of the SPS-MSF tapioca grits ranged from 60% to 83%, with 90 g SPS: 2 g MSF tapioca grits having the highest BD and 94 g SPS:11.66 g MSF tapioca grits having the lowest BD (Table 2). The BD of the tapioca grits was higher than that of tapioca supplemented with soy flour (Otegbayo *et al.*, 2013) and tiger nut flour (Adeoti *et al.*, 2017) but within the range of values reported by Ijeoma *et al.* (2016) for tapioca grits produced from different cassava varieties. The BD of the tapioca grits from 90 g SPS: 2 g MSF, 9.66 g SPS: 6 g MSF, 94 g SPS: 0.34 g MSF, and CS, on the other hand, did not differ significantly ($p>0.05$). The lower BD suggests that fewer food samples could be packaged in consistent volumes to ensure cost-effective packaging (Awoyale *et al.*, 2019). Additionally, the low BD of the tapioca from 94 g SPS: 11.66 g MSF blends may be advantageous in the formulation of infant food, where high nutritional density to low bulk is necessary (Ijioma *et al.*, 2016). From this investigation, it was also discovered that adding MSF decreased the BD of the SPS-MSF tapioca grits. This finding is consistent with those made by Otegbayo *et al.* (2013) when they added soy flour to tapioca, and by Adeoti *et al.* (2017), when they added tiger nut flour to tapioca.

In situations where the moisture content is low, a product's ability to associate with water is expressed by the WAC (Awoyale *et al.*, 2019). The WAC varies with shape, presence of protein, carbohydrate, lipids, pH, and salt (Adeoti *et al.*, 2017). It is also the ability of the food particles to entrap large amounts of water, such that exudation is minimized (Onyeneke, 2019). The SPS tapioca grits' WAC (518.50%) was much higher than the CS's (293%) (Table 2). The highest WAC was found in tapioca grits made from 98 g SPS: 2 g MSF (288.50%), while the lowest was found in those made from 98 g SPS: 10 g MSF (108.50%). In terms of WAC, there was not a significant difference between CS tapioca grits and 98g SPS: 2 g MSF ($p>0.05$) (Table 2). In the preparation of soups, gravies, doughs, custards, and sausages, where it is important to incorporate water without causing the protein to dissolve, SPS tapioca grits may be a useful ingredient, because of their high WAC (Otegbayo *et al.*, 2013). The differences in the WAC of the SPS-MSF tapioca grits may be caused by variations in the MSF inclusion. In comparison to the WAC reported by Ijioma *et al.* (2016) for various cassava varieties, the WAC of the CS tapioca grits in this study was higher. The WAC recorded for the soy-flour supplemented tapioca (Otegbayo *et al.*, 2013) fell within the range of values reported for tapioca grits in the current investigation at 98 g SPS:10 g MSF, 99.66 g SPS:6 g MSF, 90 g SPS:10 g MSF, and 94 g SPS:11.66 g MSF. In contrast to this study, tiger-nut-supplemented tapioca (Adeoti *et al.*, 2017) had a lower WAC. Also, the WAC of the SPS-MSF tapioca grits decreased as the MSF inclusion level increased, which is not in agreement with what Otegbayo *et al.* (2013) observed when tapioca grits were supplemented with soy flour.

Similar to the WAC, there was no significant difference statistically ($p>0.05$) between the OAC in the SPS tapioca grits (70%) and the CS (64%). With 90 g SPS:10 g MSF tapioca grits having the highest OAC and 99.66 g SPS:6 g MSF having the lowest, the SPS-MSF tapioca grits OAC ranged from 59.50 to 81.50% (Table 2). Although higher than the values published by Otegbayo *et al.* (2013) for tapioca grits supplemented with soy flour, the OAC of all the tapioca grits in this study was within the range of values reported by Ijioma *et al.* (2016) for tapioca produced from different cassava varieties. According to Zhang *et al.* (2021), the interaction between fat and the non-polar chain of protein, as well as the actual physical trapping of oil, are responsible for the mechanism of OAC. This indicates that the MSF may have contributed to the increased OAC in the 90 g SPS: 10 g MSF tapioca grits. It is essential to note that, with the exception of SPS-MSF tapioca grits made from 90 g SPS: 10 g MSF and 94 g SPS: 11.66 g MSF, there was no significant difference ($p>0.05$) in the OAC of any of the SPS-MSF tapioca grits compared to that of the CS.

Intermolecular forces, the presence of surfactants, and other associated compounds all have an impact on the SI, which is related to how much amylose is leached from starch granules during swelling (Awoyale *et al.*, 2019). Though not statistically significant ($P>0.05$), the SI of the SPS tapioca grits (14%) was higher than that of the CS (13%). The SPS-MSF tapioca grits produced from 94 g SPS: 0.34 g MSF and 98 g SPS:2 g MSF have the highest SI (8%) and that of 90 g SPS:10 g MSF the lowest (2%) (Table 2). Since starch degrades more quickly at higher SIs, there are more soluble molecules in the starch (Kumoro *et al.*, 2012). Because of its higher SI, it was hypothesized that the tapioca grits from the SPS could deteriorate more quickly than those from the CS. The SPS-MSF tapioca grits with a higher SI may have the same effect. The SI for tapioca grits enhanced with tiger nuts reported by Adeoti *et al.* (2017) fell within the range of values found in the current investigation.

The SWP is a measure of hydration capacity that describes how much the interior structure of starch granules is exposed to the action of water (Kumar and Khatkar, 2017). The expansion that comes along with the spontaneous intake of water is also implied (Adepeju *et al.*, 2014). The SWP of the SPS tapioca grits was the highest

(13.75%), while that of the CS was the lowest (10.55%). The 98 g SPS: 2 g MSF (12.70%) of the SPS-MSF tapioca grits had the highest SWP, while 94 g SPS: 11.66 g MSF (5.58%) had the lowest (Table 2).

Table 2. Functional properties of tapioca grits.

Samples gSPS:gMSF	Bulk density (%)	Water Absorption Capacity (%)	Oil Absorption Capacity (%)	Solubility index (%)	Swelling Power (%)
98:10	71.00±0.00^{b}	108.50±0.71^{h}	62.50±0.71^{c-e}	7.00±1.41^{cd}	9.48±0.14^{ef}
90:2	83.00±0.00^{a}	210.50±0.71^{e}	61.00±1.41^{de}	6.00±0.00^{cd}	12.23±0.07^{bc}
99.66:6	81.50±0.02^{a}	150.50±2.12^{f}	59.50±2.12^{e}	9.65±0.49^{b}	8.43±0.01^{f}
88.34:6	74.00±0.04^{b}	208.50±2.12^{e}	70.00±2.83^{b-d}	6.35±0.49^{cd}	8.80±0.20^{f}
94:0.34	81.50±0.02^{a}	259.50±3.54^{c}	72.00±2.83^{a-c}	8.00±0.00^{bc}	10.71±0.66^{de}
98:2	72.50±0.02^{b}	288.50±0.71^{b}	68.00±2.83^{b-e}	8.00±0.00^{bc}	12.70±0.08^{ab}
94:6	73.70±0.03^{b}	226.30±3.47^{d}	75.00±4.03^{ab}	5.10±1.20^{d}	11.38±0.77^{cd}
90:10	61.00±0.00^{c}	163.00±25.46^{f}	81.50±9.19^{a}	2.00±0.00^{e}	6.26±0.14^{g}
94:11.66	60.00±0.01^{c}	124.50±12.02^{g}	76.50±9.19^{ab}	2.30±0.42^{e}	5.58±0.42^{g}
SPS	80.00±0.04^{a}	518.50±6.36^{a}	70.00±4.24^{b-d}	14.00±0.00^{a}	13.75±0.21^{a}
CS	83.00±0.00^{a}	293.00±8.49^{b}	64.00±0.00^{c-e}	13.00±1.41^{a}	10.55±0.58^{de}
Mean	74.40	230.43	70.67	6.79	10.36
p level	***	***	**	***	***

SPS-Sweet potato starch; MSF-Moringa seed flour; CS-Cassava starch, ***$p<0.001$; **$p<0.01$
Means with the same letters in the same column are not significantly different ($p>0.05$)

The SWP of tapioca grits supplemented with tiger nut (Adeoti *et al.*, 2017) and soy flour (Otegbayo *et al.,* 2013) was within the range of values found in the current study. While lipids in the MSF may have contributed to the formation of an insoluble amylose-lipid complex with amylose during swelling and gelatinization of the MSF-substituted tapioca grits, the lower SWP observed in 94% SPS:11.66% MSF tapioca grits may also be attributable to the protein-amylose complex (Reddy *et al.,* 2016). This finding is in agreement with Farooq *et al.* (2021), who reported that the development of amylose-lipid complexes typically affects food products' functioning by lowering SWP and altering rheological characteristics.

Pasting properties of tapioca grits

Since the tapioca grits will be reconstituted in hot water before eating, the pasting properties of the tapioca grits are significant in predicting the behaviour of the gruel during and after cooking (Awoyale *et al.,* 2019). Table 3 depicts the tapioca grits made from SPS, CS, and blends of SPS and MSF.

Table 3. Pasting properties of tapioca grits.

Samples gSPS:gMSF	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak time (min)	Pasting Temperature (°C)
98:10	201.92 ± 0.35^{e}	173.34 ± 0.94^{h}	28.59 ± 0.59^{g}	229.42 ± 0.71^{f}	56.09 ± 0.23^{f}	5.90 ± 0.04^{a}	81.53 ± 0.04^{a}
90:2	407.38 ± 1.12^{a}	271.08 ± 2.12^{b}	136.29 ± 1.00^{b}	401.42 ± 1.29^{b}	130.34 ± 0.83^{b}	4.64 ± 0.05^{de}	79.43 ± 0.53^{a}
99.66:6	256.88 ± 3.01^{d}	204.09 ± 0.59^{g}	52.79 ± 3.59^{f}	281.21 ± 3.71^{e}	77.13 ± 4.31^{e}	5.44 ± 0.05^{b}	81.10 ± 0.49^{a}
88.34:6	323.21 ± 4.42^{c}	234.50 ± 2.94^{e}	88.71 ± 1.47^{de}	343.54 ± 4.54^{c}	109.05 ± 1.59^{cd}	5.00 ± 0.00^{c}	79.80 ± 0.07^{a}
94:0.34	417.63 ± 2.54^{a}	302.71 ± 1.71^{a}	114.92 ± 0.83^{c}	456.59 ± 2.35^{a}	153.88 ± 0.64^{a}	4.77 ± 0.05^{cd}	78.63 ± 0.67^{a}
98:2	426.17 ± 0.71^{a}	262.00 ± 1.06^{c}	164.17 ± 1.77^{a}	384.13 ± 7.36^{b}	122.13 ± 8.42^{bc}	4.44 ± 0.05^{e}	78.20 ± 0.00^{a}
94:6	355.08 ± 11.80^{b}	248.09 ± 3.78^{d}	94.80 ± 2.58^{d}	355.18 ± 16.18^{c}	117.60 ± 11.16^{bc}	5.39 ± 0.20^{b}	82.40 ± 3.30^{a}
90:10	270.21 ± 3.01^{d}	200.34 ± 1.89^{g}	69.88 ± 4.89^{ef}	312.17 ± 5.66^{d}	111.84 ± 7.54^{cd}	4.87 ± 0.00^{cd}	59.45 ± 4.38^{b}
94:11.66	273.38 ± 3.36^{d}	203.17 ± 0.47^{g}	70.21 ± 2.89^{ef}	301.17 ± 5.89^{de}	98.00 ± 5.42^{d}	5.07 ± 0.09^{c}	65.48 ± 21.53^{b}
SPS	332.88 ± 40.13^{bc}	162.04 ± 0.06^{i}	170.84 ± 40.18^{a}	228.08 ± 3.89^{f}	66.04 ± 3.83^{ef}	4.34 ± 0.19^{e}	57.40 ± 9.69^{b}
CS	271.88 ± 1.94^{d}	221.08 ± 3.18^{f}	50.80 ± 5.13^{f}	354.38 ± 4.42^{c}	133.30 ± 1.24^{b}	5.00 ± 0.10^{c}	77.85 ± 0.64^{a}
Mean	330.46	231.65	94.74	337.86	109.72	5.09	76.72
p level	***	***	***	***	***	***	**

SPS-Sweet potato starch; MSF-Moringa seed flour; CS-Cassava starch; ***$p<0.001$; **$p<0.01$

Means with the same letters in the same column are not significantly different ($p>0.05$)

The peak viscosity of the tapioca grits was 330.46 RVU, trough viscosity 231.08 RVU, breakdown viscosity 94.74 RVU, final viscosity 337.86 RVU, setback viscosity 109.72 RVU, peak time 5.09 min, and pasting temperature 76.72°C ($p<0.05$). Except for the peak (332.88 RVU) and breakdown (170.84 RVU) viscosities of the SPS tapioca grits, which were higher than that of the CS, all of the CS tapioca grits' pasting properties were higher compared to those of the SPS.The sample's peak viscosity, which develops during or shortly after the heating phase, is at its highest level (Awoyale *et al.*, 2019). Additionally, Awoyale *et al.* (2019) also added that the peak viscosity shows the viscous load that will probably be experienced while mixing when turning tapioca grits into gruel. This suggests that due to their high peak viscosity, SPS tapioca grits would be more viscous than CS tapioca grit when made into a gruel for consumption. Similarly, 98 g SPS:2 g MSF tapioca grits (426.17 RVU) may be more viscous than those made from 98 g SPS:10 g MSF (201.92 RVU) (Table 3). The high peak viscosity of the tapioca grits may be linked with its high swelling power. This is because a positive and significant correlation ($p<0.05$, $r = 0.61$) existed between the swelling power and the peak viscosity of the tapioca grits (Table 4). Adeoti *et al.* (2017) observed peak viscosities for tapioca grits enhanced with tiger nuts and CS that were lower than those of our investigation. In contrast, Otegbayo *et al.* (2013) showed higher peak viscosities for CS tapioca grits than in this study. The CS tapioca grits' peak viscosity was not significantly different from that of the 99.66 g SPS:6 g MSF, 90 g SPS:10 g MSF, and 94 g SPS:11.66 g MSF ($p>0.05$).

Table 4. Pearson correlation of the functional and pasting properties of the tapioca grits, and sensory acceptability of the gruel.

Attributes	Bulk density	WAC	OAC	SI	SWP	Overall acceptability
Peak viscosity	0.35	0.42	0.07	0.05	0.61*	-0.38
Trough viscosity	0.32	-0.07	0.00	-0.17	0.26	-0.49
Breakdown viscosity	0.27	0.73*	0.09	0.25	0.71*	-0.15
Final viscosity	0.29	-0.03	0.08	-0.16	0.20	-0.59
Setback viscosity	0.21	0.02	0.21	-0.15	0.12	-0.67*
Peak time	-0.18	-0.70*	-0.21	-0.24	-0.46	0.38
Pasting temperature	0.45	-0.39	-0.59	0.06	0.20	0.01
Overall acceptability	0.31	0.16	-0.42	0.46	0.25	1.00

WAC - water absorption capacity; OAC - oil absorption capacity; SWP - swelling power; SI - solubility index

The sample is subjected to a period of steady temperature (at 95°C) and mechanical shear stress during the holding phase of a standard pasting test. Amylose molecules typically leach out into the solution and align in the direction of the shear as a result, further disrupting the starch granule (Awoyale *et al.*, 2019). The paste's resistance to breakdown, while cooling is measured by the trough viscosity (Awoyale *et al.*, 2019). As a result of its higher trough viscosity than SPS, tapioca gruel made from CS may tolerate breaking down during cooling. In a similar vein, 94 g SPS: 0.34 g

MSF (302.71 RVU) tapioca gruel may tolerate breakdown, while cooling as opposed to 98 g SPS: 10 g MSF (173.34 RVU) tapioca gruel (Table 3). Compared with the tapioca grits enriched with soy flour and the tiger nut reported by Otegbayo *et al.* (2013) and Adeoti *et al.* (2017), the trough viscosity of the tapioca grits in this study was higher.

The sample's capacity to endure shear stress and heating during cooking is indicated by the breakdown viscosity. The sample's capacity to endure heating and shear stress during cooking decreases with increasing breakdown viscosity (Awoyale *et al.*, 2019). Because SPS tapioca gruel (170.84 RVU) had a higher breakdown viscosity than CS, which had a lower breakdown viscosity (50.80 RVU), it may be inferred that it might not be able to tolerate heating and shear stress during cooking. In a similar vein, gruel made from tapioca grits with a ratio of 98 g SPS:10 g MSF (28.59 RVU) may tolerate heating and shear stress during cooking, as opposed to gruel made from tapioca grits with a ratio of 98 g SPS:2 g MSF (164.17 RVU) (Table 3). The high breakdown viscosity of the 98 g SPS:2 g MSF tapioca grits may be attributed to its high WAC and SWP. This is because a positive and significant correlation existed between the breakdown viscosity and the WAC ($p<0.05$, $r = 0.73$) and SWP ($p<0.05$, $r = 0.71$) of the tapioca grits (Table 4). It's interesting to note that the CS tapioca grits' breakdown viscosity was not significantly different from that of 99.66 g SPS:6 g MSF, 90 g SPS:10 g MSF, and 94 g SPS:11.66 g MSF ($p>0.05$).

The most widely used metric to assess the quality of a starch-based sample is its final viscosity since it shows whether the material can gel when heated (Awoyale *et al.*, 2019). The SPS tapioca grits may have a low tendency to retrograde because of their low final viscosity (228.08 RVU), in comparison to their peak viscosity (Awoyale *et al.*, 2019). This may not be the case for the CS tapioca grits, which had a higher final viscosity (354.38 RVU). Similar to the previous example, the 94 g SPS: 0.34 g MSF tapioca grits (456.59 RVU), with a high final viscosity, may have a higher tendency for the gruel to retrograde than the 98 g SPS:10 g MSF (229.42 RVU) with lower final viscosity (Table 3). The CS tapioca grits' final viscosity was not significantly different from that of the 94 g SPS:6 g MSF and the 88.34 g SPS:6 g MSF ($p>0.05$).

The setback or viscosity of the cooked paste is represented by the viscosity at 50°C after cooling. At this stage, the molecules of starch are retrograded or rearranged. Greater resilience to retrogradation is indicated by a lower setback viscosity as the paste cools (Awoyale *et al.*, 2019). In contrast to CS tapioca grits (133.30 RVU), tapioca gruel made from SPS tapioca grits (66.04 RVU) may withstand retrogradation. Additionally, the low setback viscosity of the tapioca gruel formed from 98 g SPS: 10 g MSF tapioca grits (56.09 RVU), as opposed to that made from 94 g SPS: 0.34 g MSF (153.88 RVU) with a larger setback viscosity, may allow it to withstand retrogradation (Table 3). Since there was no significant difference ($p > 0.05$) in the setback viscosities of the 94 g SPS: 6 g MSF, 98 g SPS: 2 g MSF, and 90 g SPS:2 g MSF, a similar setback viscosity to that of the CS tapioca grits were observed.

Starch granules absorb a lot of water and expand several times their original size when starch or starch-based foods are cooked in water past a threshold temperature.

When a specific starch is exposed to a crucial temperature, known as gelatinization, the starch goes through an irreversible process (Awoyale *et al.,* 2019). The minimal temperature necessary to cook a specific food sample is also measured by the pasting temperature, which can have an impact on the stability of other ingredients in a recipe, providing information about energy expenditures (Awoyale *et al.*, 2019). In comparison to the CS tapioca grits (77.85^{o}C), the SPS tapioca grits required a lower temperature (57.40^{o}C) to be cooked into gruel (Table 3). A higher temperature of 82.40^{o}C and a lower temperature of 59.45^{o}C were also needed to cook the 94 g SPS:6 g MSF and 90 g SPS:10 g MSF tapioca grits into gruel, respectively (Table 3). The pasting temperature of the CS tapioca grits in this study was higher than that of the tapioca grits reported by Otegbayo *et al.* (2013). Although, a comparable range of values was observed in the pasting temperatures of the SPS and MSF blends of tapioca grits. Also, most of the results for the pasting temperature of the CS and the tiger-nut-enriched tapioca grits published by Adeoti *et al.* (2017) were higher than those of this investigation. The different methods used for the partial gelatinization of starch granules during roasting may be responsible for variations in pasting temperatures (Otegbayo *et al.,* 2013). The tapioca grits can, however, form gruel in hot water below the boiling point and for less than six minutes because the pasting temperature of all the tapioca grits was generally lower than the boiling point of water. This represents remarkable energy cost savings on a commercial basis. A negative and significant correlation ($p < 0.05$, r = -0.70) existed between the WAC and the peak time of the tapioca grits (Table 4); thus, a higher WAC in the tapioca grits may also reduce the time taken to form a gruel during cooking.

Sensory attributes of tapioca gruel

Table 5 depicts the sensory attributes of the tapioca gruel. The results showed that all the tapioca gruels were not significantly different ($p > 0.05$), except for appearance ($p < 0.05$) and mouthfeel ($p < 0.01$), which were significantly different. This implies that of all the tapioca gruel sensory attributes, it was only the appearance and mouthfeel that differed. Although all the sensory attributes of the SPS-MSF tapioca gruel fall within the likeness range, tapioca gruel produced from 98 g SPS:10 g MSF blends (7.91) was very much liked compared to the CS tapioca gruel (7.09) in terms of the overall acceptability. This may be linked to the low setback viscosity of the tapioca gruel, as a negative and significant correlation (p<0.05, r= -0.67) exists between the setback viscosity of the tapioca grits and the overall acceptability of the gruel (Table 4). When gelatinized starch is cooled, the disrupted amylose and amylopectin chains can gradually re-associate into different ordered-structure in a process termed retrogradation (Wang and Copeland, 2013) indicated by the setback viscosity. The higher the setback viscosity, the higher the degree of retrogradation, which is usually accompanied by increased viscosity and turbidity of paste (Adeboye *et al.,* 2019). Thus, the negative and significant correlation between the setback viscosity and the overall acceptability of the tapioca gruel.

Table 5. Sensory qualities of tapioca gruels.

Samples gSPS:gMSF	Appearance	Taste	Mouthfeel	Flavor	Texture	Color	Overall acceptability
98:10	7.36 ± 0.81^{ab}	7.82 ± 1.08^{a}	7.18 ± 0.75^{a}	6.82 ± 0.75^{a}	6.27 ± 1.10^{a}	6.82 ± 1.47^{a}	7.91 ± 0.54^{a}
90:2	6.27 ± 1.01^{bc}	$6.73\pm0.90^{a-c}$	$5.91\pm1.30^{b-d}$	6.82 ± 1.25^{a}	6.00 ± 1.61^{a}	7.00 ± 0.63^{a}	7.09 ± 1.45^{a}
99.66:6	$6.64\pm1.43^{a-c}$	6.27 ± 2.00^{bc}	$6.73\pm1.56^{a-c}$	6.91 ± 1.58^{a}	6.27 ± 1.68^{a}	6.64 ± 1.12^{a}	7.64 ± 1.12^{a}
88.34:6	6.10 ± 1.10^{c}	6.10 ± 1.60^{bc}	$6.30\pm1.25^{a-d}$	6.40 ± 1.07^{a}	6.10 ± 1.10^{a}	6.20 ± 1.23^{a}	6.90 ± 1.29^{a}
94:0.34	7.64 ± 1.29^{a}	7.36 ± 0.92^{ab}	$6.36\pm1.03^{a-d}$	6.64 ± 1.12^{a}	6.09 ± 1.58^{a}	6.82 ± 1.08^{a}	7.36 ± 1.96^{a}
98:2	$7.00\pm1.41^{a-c}$	6.36 ± 1.29^{bc}	5.36 ± 0.81^{d}	6.09 ± 1.38^{a}	5.91 ± 1.14^{a}	6.36 ± 1.63^{a}	7.00 ± 1.10^{a}
94:6	$6.62\pm1.22^{a-c}$	6.47 ± 1.36^{bc}	6.80 ± 1.39^{ab}	6.64 ± 1.37^{a}	6.73 ± 1.33^{a}	6.38 ± 1.46^{a}	7.20 ± 1.27^{a}
90:10	$6.73\pm1.35^{a-c}$	6.09 ± 1.87^{bc}	$5.91\pm1.30^{b-d}$	6.55 ± 1.29^{a}	5.91 ± 1.14^{a}	6.64 ± 1.36^{a}	7.09 ± 1.70^{a}
94:11.66	5.91 ± 1.30^{c}	5.91 ± 1.58^{c}	$5.91\pm1.45^{b-d}$	6.82 ± 1.08^{a}	5.64 ± 1.36^{a}	6.82 ± 1.40^{a}	6.91 ± 1.30^{a}
SPS	6.09 ± 1.30^{c}	6.27 ± 1.27^{bc}	6.82 ± 1.33^{ab}	6.64 ± 1.36^{a}	6.27 ± 1.79^{a}	6.73 ± 1.42^{a}	7.73 ± 1.42^{a}
CS	$6.73\pm1.01^{a-c}$	$6.82\pm1.40^{a-c}$	5.55 ± 1.21^{cd}	5.73 ± 1.56^{a}	5.73 ± 1.10^{a}	5.82 ± 1.33^{a}	7.09 ± 1.14^{a}
Mean	6.64	6.54	6.40	6.57	6.26	6.52	7.25
p level	*	NS	**	NS	NS	NS	NS

SPS-Sweet potato starch; MSF-Moringa seed flour; CS-Cassava starch; **$p<0.01$; *$p<0.05$; NS-Not significant ($p>0.05$)

9=extremely like; 8=like very much; 7=moderately; 6=like slightly; 5=neither like nor dislike; 4=dislike slightly; 3=dislike moderately; 2=dislike very much, 1=extremely dislike

Means with the same letters in the same column are not significantly different ($p>0.05$)

Conclusions

The water absorption capacity and swelling power of the 100% SPS tapioca grit were higher than that of the CS tapioca grit. Conversely, the pasting properties of the CS tapioca grits were higher than that of the 100% SPS tapioca grits, except for the peak and breakdown viscosities, where the 100% SPS tapioca grit was higher. The MSF inclusion increased the bulk density and oil absorption capacity in some of the SPS-MSF tapioca grits, while the water absorption capacity, solubility index, and swelling power decreased. Also, the SPS-MSF tapioca grit's peak, trough, final, and setback viscosities, peak time, and pasting temperature increased with MSF inclusion, and the breakdown viscosity decreased. Although all the sensory attributes of the SPS-MSF tapioca gruel fall within the likeness range, tapioca gruel produced 98%SPS and 10%MSF blends was very much liked compared to the CS tapioca gruel in terms of the overall acceptability. Therefore, the addition of MSF to the SPS-MSF tapioca grits influences most of the rheological properties and sensory acceptability, which may allow consumers to choose based on the level of viscosity preferred in the cooked gruel.

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