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Chemical and functional properties of nutrient-dense beverages developed from underutilised crops

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Abstract

Beverages are typically seen as wholesome snacks that can be included in a daily diet. Despite being part of the regular diet, the majority of these beverages are low in nutrients and high in calories. Worldwide, a variety of industrial processes, raw ingredients, and microorganisms are used to manufacture fermented food. Many indigenous or traditional fermented foods and beverages are still prepared today as a form of domestic art. They are created in small businesses, communities, and homes. Among the fermented foods that are important to people's diets worldwide are beverages that might have a non-dairy origin. In this study, *Moringa oleifera* Leaf Powder (MoLP) was used to fortify two beverages, including *Amasi* (Bambara groundnut) and *Mageu* (sorghum), at 0% (control), 1%, and 5%. After fortifying the fermented and unfermented variations, the beverages' chemical, and functional properties were analysed. The effects of MoLP (1% and 5%) on the stress, viscosity, and torque characteristics of *Amasi* were significant ($p \leq 0.05$). For all of the samples, *Amasi* and *Mageu's* values for protein, ash, and moisture increased significantly ($p \leq 0.05$) due to the inclusion of MoLP. These findings indicate that MoLP-fortified beverages can act as a source of nutrients to address micronutrient deficiencies in children and adults.

Keywords

Bambara groundnut, Sorghum, *Moringa oleifera* Leaf Powder (MoLP), Fortification, Malting, Fermentation, functional

Introduction

Traditional Southern African beverages like *Amasi* and *Mageu* are fermented conventional beverages that have recently gained momentum in the market (1-3). Several allergies, including lactose intolerance, are associated with dairy products and different dietary needs or lifestyles. Customers in these situations prefer non-dairy alternatives to the original product, which is a vegan lifestyle or shelf-stable non-dairy products. Among these products, non-dairy food and drink have attracted the most interest. One of the critical reasons for this sudden switch to non-dairy goods, where many consumers are switching from traditional dairy beverages to non-dairy beverages, is that dairy products contain saturated fats, which are problematic because they are related to heart disease. However, the issue with non-dairy beverages is that they are nutrient-deficient compared to traditional dairy beverages.

Amasi is a fermented milk product that can also be made from

Bambara groundnut (*Vigna subterranean*) (2), and *Mageu* (also known as *mahewu*, *amahewu*, *marewu*, or *magou*) is a popular non-alcoholic fermented beverage or gruel (4) that is commonly consumed in most parts of Southern Africa such as South Africa, Lesotho and Zimbabwe (5-7) Although *Mageu* is made from Maize, especially in South Africa, it is also made from Sorghum and millet in countries such as Zimbabwe (4). This indigenous food product contains healthy nutrients such as protein, carbohydrates, and fat. Many people depend on indigenous products in developing countries to access healthy or sufficient nutrients.

Food fortification is a required method that has gone a long way toward combating and reducing micronutrient deficiencies. Adding minerals and vitamins to staple foods ensures more people can access essential nutrients without changing their food consumption behaviors (8). The process of food fortification involves the incorporation of macro- or micronutrients to improve the nutritional quality of foodstuff. Foods generally fortified are wheat flour, wheat flour-based and cereal-based. Typically, when food is fortified, the fortificant provides limited functionality. However, the demand for ingredients whose single use provides many functions is increasing (9).

Moringa oleifera Lam. is a crop native to Northern India, known to be rich in micro and macronutrients. Its leaf powder serves as a food fortificant in various products, including beverages, maize gruel, and yogurts. It was found to positively contribute to improving the nutritional value of fortified foods (10). Due to its wide range of nutrients, *M. oleifera* is a significant vegetable in people's diets in many underdeveloped nations. Numerous flavonoids and phenolic acids in *Moringa* have health-promoting properties (11). Consequently, there is a reduced prevalence of malnutrition among both children and older people. Limited access to beverages with high nutritional value is a challenge faced by many individuals in Southern Africa. Nonetheless, incorporating *M. oleifera* (e.g., fruits, leaves, flowers, and immature pods) (12, 13) into these beverages could mitigate this issue, thanks to its appealing taste and the health benefits of specific components. Therefore, this study aims to look at the effect of fortifying the beverages identified above (*Amasi* and *Mageu*) with *Moringa oleifera* Leaf Powder (MoLP), emphasizing their chemical and functional properties.

Materials and Methods

2.1 Materials

Sorghum (*Sorghum bicolor*) was sourced from Agricol, South Africa. At the same time, *M. oleifera* leaf powder was purchased from Supa Nutri, a South African company that sources products from South Africa and other Southern African Development Community (SADC) countries. The Bambara groundnut (BGN) seeds were purchased from Triotrade Johannesburg, South Africa. Other materials, including starter cultures of *Lactobacillus leichmannii* and *L. plantarum,* were obtained from Anatech, South Africa. The chemicals used in this study were of analytical grade (Sigma-Aldrich, Johannesburg, South Africa). The equipment used is available at the Department of Food Technology and Oxidative Stress Research Centre of the Cape Peninsula University of Technology, Cape Town.

2.2 Preparation of Amasi

A commercial fermented milk (*Amasi*) product obtained from a local retail shop was used as a control sample. The BGN milk was prepared using a patented formulation from the Cape Peninsula University of Technology. The BGN milk was pasteurized, cooled, and inoculated with a pure starter culture of *L. leichmannii*. After dividing the inoculated BGN milk into three portions, 1% and 5% (w/v), MoLP was added to two portions, while 0% was used as the control and the unfermented BGN milk sample. The samples were placed in an incubator at 37°C for three days until the desired fermentation quality and pH of 4.5; in particular, a smooth, yogurt-like texture was attained (14).

2.3 Preparation of Mageu

Mageu was prepared using room temperature water mixed with 8% (w/w) Sorghum grain. It was milled using a hammer mill (Bauermeister, Bauermeister Inc., Vernon Hills, IL, USA). This slurry was cooked in steel pots at 85-90 °C for 20 to 30 minutes. The porridge was cooled to 25 °C before being transferred to bioreactors and inoculated with 12% *Lactobacillus plantarum*. The inoculated porridge was allowed to ferment for 72 hours at 37 °C. When the pH reached 3-3.4, the *Mageu* was then pasteurised. Sorghum *Mageu* was produced with both malted and unmalted Sorghum grains. These were fortified with 0%, 1%, and 5% MoLP. Additionally, unmalted and malted unfermented *Mageu* samples were made and stored as controls. All the samples were stored in the fridge at 4 °C until the analysis phase was carried out (15).

2.4. Analyses

2.4.1 Chemical composition of Moringa oleifera Leaf Powder (MoLP) and the beverage products

Moisture and ash contents of the MoLP were analysed according to AOAC Method 934.01 (AOAC, 2005) and the Soxhlet method (AOAC 954.02) for fat extraction. By doing so, total carbohydrate (TC) was calculated by difference (TC%) = 100 - (moisture + protein + fat + ash). The nitrogen content of the MoLP was determined using the Kjeldahl method (AOAC, 2000 method 990.03) (16).

2.4.2 Colour parameters of beverages products

The L*, a* and b* values of beverage products were measured using a colorimeter. Prior to taking readings, the colorimeter was calibrated using black and white standard plates. Each sample had ten readings taken randomly, and the average value with standard deviation was used. The L* scale measures whiteness and ranges from black at 0 to white at 100. The a* measures green when it is negative and red when it is positive, while the b* measures blue when it is negative and yellow when it is positive (17).

2.4.3 Total Phenolic Content (TPC) and antioxidant activity of beverages products

2.4.3.1 Total Phenolic Content (TPC) of beverages products

The total concentration of phenol (TPH) within the extracts was determined according to the Folin Ciocalteu method with Gallic acid (GA) as the standard and was then expressed in mg as GA equivalents (GAE) /10 g of extract (18). 20 µl of sample extract was added to 1.58 ml distilled water, and then 100 µl of Folin-Ciocalteu reagent was added. After 1 min, 300 µl of 20% sodium carbonate solution was added. After 2 hours of incubation at room temperature, the resulting blue colour was read at an absorbance of 765 nm. Samples were analysed in triplicate (19). TPC was determined from the calibration curve of GA.

2.4.3.2 Oxygen Radical Absorbance Capacity (ORAC) of beverages products

Using a fluorescence spectrophotometer, this approach measures the antioxidant activity of the samples up until zero fluorescence is reached. The data is presented as the ORAC value, representing the net protection area under the quenching curve in the presence of an antioxidant. By dividing the area under the sample curve by the area under the Trolox curve, the ORAC value is determined. The two areas are added together by deducting the area under the empty curve. The net protective area that one µM of trolox in final concentration provides equals one ORAC unit. The results are presented in Trolox equivalents when the sample's area under the curve is contrasted with Trolox's area under the curve. The ORAC approach is distinctive in its analysis since it calculates the area under the curve by combining the inhibition time and the level of inhibition as a single number. Dilution doesn't influence the ORAC technique (20).

2.4.4 Determination of pH and total titratable acidity (TTA) of Amasi products

The pH of the beverage samples was determined using an electronic pH meter (Jenway, UK), calibrated with buffer solutions at pH of 4 and 7, with a food penetration probe. Total titratable acidity (TTA) was determined on 10 g of beverage homogenized with 90 ml of distilled water and expressed as the amount (ml) of 0.1 M NaOH to get a pH of 8.3.

2.4.5 Rheological analysis of beverages products

The beverage analysis was conducted using a Rheolab QC of C-PTD 180/Air/QC model from Anthon Paar in the USA, using a C-CC27 measuring cup and ST 22.02-4V probe at 5 ° C. The sample was transferred to the holding chamber of the equipment. The chamber was filled until the graduation mark, and a spindle was inserted to induce shear stress on the sample. This was connected to the equipment rotated under a given temperature range and time. A minimum of 30 readings were taken for each sample. The equipment measured viscosity, temperature, and torque, respectively, for each sample. Note that shear stress is the amount of force per unit area perpendicular to the axle of the member. In this case, the members of the liquid investigated, namely *Amasi* and *Mageu* (20).

2.5 Statistical analysis

All analyses were done in triplicates. ANOVA was carried out on the data obtained, whereas Duncan's multiple range tests were used to separate means and significant differences ($p \leq 0.05$) within the means. Significant differences were defined at ($p \leq 0.05$). The data obtained were recorded as mean values with standard deviation (mean ± standard deviation).

Results and Discussion

3.1 Chemical composition of MoLP, Amasiand Mageu

3.1.1 The chemical composition of MoLP

The *M. oleifera* leaf powders were analyzed for moisture, protein, fat, ash, and carbohydrate contents, with the values shown in Table 1 are similar to the trends reported earlier (22). Differences in protein and fat contents could be attributed to plant varieties, growing climates, ripening stages, and extraction methods. The high protein yield rate indicates that the *Moringa* leaves are likely to be utilised for specific applications in the food industry. The leaves contain more protein, making them a good and cheap source of protein supplements. An acceptable level of moisture content was present in the leaves after drying, and the ash contents also exhibited a similar trend, showing an appreciable amount of minerals in the leaves.

Table 1. Chemical composition of MoLP

SAMPLE	MOLP
PROTEIN	24.96±0.39
FAT	27.87±1.57
CARBOHYDRATE	30.14±1.95
ASH	10.55±0.16
MOISTURE	6.48 ±0.11

3.1.2 Chemical composition of Amasi

The result of the chemical composition of the different *Amasi* samples is presented in Table 2. The protein content of the sample varied across different concentrations, ranging from the control (9.84 ± 1.43^{a}) to 5% MoLP (26.53 ± 0.69^{ab}), and a significant difference ($p \leq 0.05$) in protein content was observed. The protein content of *Amasi* was relatively high in the 5% MoLP sample and relatively low in the unfermented (11.77 ± 0.06^{c}) and commercial (4.01 ± 0.50^{bc}) samples. This result confirms that MoLP may be explored to address protein energy malnutrition (PEM), especially in rural communities. The ash content of the *Amasi* was diverse in the samples used, namely the control sample (5.29 ± 1.04^{a}), 5% MoLP sample (13.83 ± 6.41^{ab}), unfermented sample (11.54 ± 10.33^{c}), and commercial sample (9.63 ± 7.20^{bc}). The results showed significant differences ($p \leq 0.05$) between all the samples regarding their ash content. The ash value measures the mineral content, which is important for bone growth, tooth development, and other bodily processes (23). This indicates that the 5% *Moringa* fortified sample is a better source of minerals among the samples. The moisture content of the *Amasi* also varied per sample, as illustrated in the following: Control (86.35 ± 0.66^{a}) to 5% MoLP (82.74 ± 1.28^{ab}), unfermented (86.68 ± 0.20^{c}) and commercial

Table 2. Protein, ash, and moisture content of *Amasi*

Sample	Protein	Ash	Moisture
Control	9.84 ± 1.43^{a}	5.29 ± 1.04^{a}	86.35 ± 0.66^{a}
1% MoLP	15.12 ± 1.90^{b}	10.64 ± 2.91^{b}	87.31 ± 0.44^{b}
5% MoLP	26.53 ± 0.69^{ab}	13.83 ± 6.41^{ab}	82.74 ± 1.28^{ab}
Unfermented	11.77 ± 0.06^{c}	11.54± 10.33^{c}	86.68 ± 0.20^{c}
Commercial	4.01 ± 0.50^{bc}	9.63 ± 7.20^{bc}	88.60 ± 0.24^{bc}

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns indicate a significant difference (p ≤ 0.05).

(88.60 ± 0.24^{bc}). The findings revealed that the samples are significantly different (p≤0.05) in their moisture content. The difference in moisture content could be due to several factors, such as MoLP exhibiting hydrophobic properties that could lend themselves to the decrease in moisture content (24). According to a study by Aguilar-Raymundo (25), the maximum moisture level of yogurt should be 84% since too much water reduces viscosity, which affects the taste and mouth feel.

3.1.3 Chemical composition of Mageu

As shown in Table 3, the results show that as the percentage of MoLP increased, the protein content of *Mageu* increased. The protein content of the 5% MoLP-fortified *Mageu*, particularly malted (33.42±1.11^{f}) and unmalted sample (33.36±2.33^{f}), was significantly higher (p ≤0.05) than that of conventional *Mageu,* control (7.70±0.33^{ab}) and malted control (11.02±1.16^{cd}). It is important to note that although information on the addition of *Moringa* to foods is increasing (10), *Moringa* powder has been reported to increase the nutritional value of other starchy food products, such as ogi (a maize-based beverage) (26). For example, adding *Moringa* to plain sorghum *Mageu,* improved the protein quality of the beverage. The moisture content of *Mageu* was also of higher (p ≤0.05) values ranging from (84.16±0.11^{f}) to (89.09±0.11^{d}) except for the malted control (90.89±0.24^{b}) and malted unfermented (90.80±0.42^{b}) of the moisture which had greater values. The moisture content obtained in this study is similar to the ones reported for (g/100 ml) of *borde* (87.29 ± 3.21), *grawa* (95.84 ± 1.10), and *tej* (95.78 ± 1.21) (27). According to the study by Elkhier (28), the moisture content of sorghum increases with increased periods of malting. *Moringa* used as fortificant has been

Table 3.Chemical composition of sorghum Mageu

Sample	Protein	Moisture	Ash
Unmalted Unfermented	6.88±0.71^{a}	87.36±0.82^{a}	0.54±0.10^{a}
Unmalted Control	7.70±0.33^{ab}	87.75±0.24^{a}	0.80±0.1^{b}
Malted unfermented	9.70±1.02^{bc}	90.80±0.42^{b}	0.66±0.10^{a}
Malted Control	11.02±1.16^{cd}	90.89±0.24^{b}	0.89±0.10^{b}
Unmalted 1%	12.72±0.97^{d}	86.44±0.44^{c}	1.07±0.01^{c}
Malted 1%	14.86±0.85^{e}	89.09±0.11^{d}	1.47±0.57^{d}
Malted 5%	33.42±1.11^{f}	85.28±0.49^{e}	2.26±0.64^{e}
Unmalted 5%	33.36±2.33^{f}	84.16±0.11^{f}	1.88±0.1^{f}

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns represents a significant difference (p ≤ 0.05).

growing, and many are reported in the literature (10,29,30), where the degree of increase in nutrient levels was also quantified. The ash contents of *Mageu* samples, particularly the malted 5% MoLP (2.26±0.64^{e}) and unmalted 5% MoLP (1.88±0.1^{f}), were also higher (p < 0.05) than the control for unmalted unfermented (0.54±0.10^{a}) and malted unfermented (0.66±0.10^{a}). This suggests that *Moringa* has the potential to enhance the nutrients of *Mageu* and similar foods (15).

3.2 CIELAB colour determination of Amasiand Mageu

3.2.1. Colour determination of Amasi

The L* value of fortified *Amasi* provided in Table 4 shows CIELAB colour readings for all the samples. The L* values mainly refer to how dark or light a sample is. The trend observed in the L* values increased from the control to the 5% *Moringa*-fortified sample. The observed physical attribute when MoLP was added to the BGN milk was that the colour of the milk changed from light brown to dark green. The green got darker at 5% than at 1%; hence 5% had a higher L* value reading than 1% and the control. The L* values were significant from 1% to 5% (p ≤ 0.05). During the experiment, the observed colour of the commercial sample was white, indicating it was brighter or lighter than the other samples (green to dark green). Hence, Table 4 shows that it had the highest reading. All the a* and b* values listed were positive because the samples were reddish and yellow. The a* and b* values of 5% were higher than the control sample and less than the 1% sample (31).

Table 4. The effects of *M. oleifera* on the colour of *Amasi*

Sample	L* values	a* values	b* values
Control	72.21 ± 0.20^{a}	8.18 ± 0.96^{a}	15.47 ± 0.64^{a}
1% MOLP	40.12 ± 1.15^{b}	3.35 ± 0.71^{b}	20.74 ± 6.09^{b}
5% MOLP	29.85 ± 0.08^{ab}	10.22 ± 2.14^{ab}	5.02 ± 3.22^{ab}
Unfermented	62.91 ± 1.01^{c}	5.72 ± 3.87^{c}	12.74 ± 2.19^{c}
Commercial	93.10 ± 0.50^{bc}	93.48 ± 0.41^{ac}	5.92 ± 4.71^{bc}

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns indicate a significant difference (p ≤ 0.05).

3.2.2. Colour determination of Mageu

L* a* and b* values of *Mageu* accessions varied from 27.72 to 62.98, 2.78 to 8.43, and 10.47 to 30.64, respectively (Table 5). Malted 5% showed the lowest L* value (27.72) with a* and b* values (3.37 and 29.01, respectively), implying the darkest colour of *Mageu*. Neither malting nor fermentation caused a significant change (p ≤0.05) in the b* (yellowness/blueness) of the samples, as seen between the unmalted unfermented control and the unmalted fermented control and additionally between the malted and unmalted controls. Even though the malted and unmalted 1% samples do not differ significantly, a significant difference is noted between the malted and unmalted 5% samples, indicating that the malted 5% sample is significantly less yellow. The b* values progressively increase with increased MoLP levels in the unmalted and malted 0%, 1%, and 5% samples. In other words, the increased enrichment with MoLP led to increased yellowness. According to Liu (32), the addition of

Table 5. Colour of sorghum Mageu.

Sample	L*	a*	b*	ΔE
Malted 5%	27.72±0.51[a]	3.37±0.53[a]	29.01±0.61[a]	40.04±0.71[a]
Unmalted 5%	27.92±0.48[a]	2.78±0.59[a]	30.64±1.04[b]	40.71±0.62[a]
Unmalted 1%	36.64±1.07[b]	5.95±0.23[b]	16.46±1.27[c]	27.08±1.09[b]
Malted 1%	38.05±0.17[c]	6.21±0.80[bc]	16.34±1.38[c]	26.67±0.43[b]
Malted Unfermented	54.31±1.48[d]	6.65±0.66[cd]	12.67±0.62[d]	8.88±0.56[c]
Malted Control	54.40±0.42[d]	9.35±0.37[e]	10.73±1.18[e]	8.70±0.50[c]
Unmalted Unfermented	62.28±1.01[e]	7.07±0.20[de]	10.47±0.38[e]	1.90±0.24[d]
Unmalted Control	62.98±0.10[e]	8.43±0.58[f]	10.76±0.27[e]	0[f] Control

Values are mean ±standard deviation. Different superscripts in rows represent a significant difference (p ≤0.05). L* indicates lightness; a*, red (+)/green(-); b*, blue(+)/yellow(-) ΔE indicates the colour difference between samples and the control (Unmalted control sample).

5–45% MoLP caused a reduction in lightness and blueness (positive b* values) and an enhancement in greenness (negative a* values). This was, therefore, expected as MoLP has a greenish-brown colour. As the findings reveal, there is no significant colour difference (ΔE) between the unmalted and malted control, 1% sample or 5% sample. The primary source of difference is MoLP fortification, which causes both a perceivable and an unacceptable colour difference. This is indicated by the ΔE falling above 1.8 (perceivable) and 3.7 (the cut-off level for acceptability) (33). ΔE increased again with increasing levels of MoLP fortification. The only sample that does not show a perceivable difference to the control used to measure colour difference – the unmalted control is the unmalted unfermented control. According to the literature, differences in perceivable colour can be classified as "very distinct" ($\Delta E > 3$), "distinct" ($1.8 < \Delta E < 3$), and "small difference" ($\Delta E < 1.8$) (33). Thus, all samples caused "very distinct" differences in colour compared to the control. Furthermore, according to a study (31), ΔE* indicates the ability of the human eye to observe such differences, which cannot perceive E values below 1.19. The DE values between 2 and 3.7 represent a reasonably perceivable but acceptable range of differences.

3.3 Oxygen Radical Absorbance Capacity and Antioxidant Results of Amasiand Mageu

3.3.1 The Oxygen Radical Absorbance Capacity Results of Amasi

It was observed in Table 6 that the ORAC value decreased and showed a significant difference in the results (p ≤0.05) from the control up to the 5% fortified *Moringa* sample. The ORAC is linked to oxygen; the oxygen in a liquid material is bound to decrease when a material is added to the liquid, reducing the moisture content of that liquid material (34). In this case, adding *Moringa oliefera* powder to the BGN milk thus decreased the moisture content of the milk and subsequently decreased the amount of free oxygen in the milk. Table 6 below shows that the control had a mean reading of 962.3867umol TE/L, which was too high compared to the 15488.0633 umol TE/L reading of the 5% *Moringa* fortified sample. The control had more free or unbound moisture content than the 5% sample, which meant that the control sample had more oxygen than the 5% sample. The commercial sample had the lowest ORAC value of 1148 umol TE/L. The reason for this relatively low value is that the commercial one is of diary origin, which contains low antioxidants, and secondly, it was not fortified with MoLP.

The Total Phenolic Content (TPC) results of *Amasi* are represented in Table 6 below. Accordingly, the phenolic content of all the samples and MoLP had a significant effect (p ≤0.05) on the antioxidant content of *Amasi*. Phenolics are a specific type of antioxidant. The total phenolic content increased from the control to the 5% *Moringa*-fortified sample. The control had a mean value of 97.18 mg/GEA/L, which was significantly lower (p ≤0.05) compared to the 1234.8733 mg/GEA/L mean reading value of 5% fortified *Moringa*. This can be attributed to the high phenolic content of *Moringa* and BGN. MoLP has a phenolic content of 0.81 ± 0.05 mg/g GAE (35) and BGN have their TPC, hence the increased TPC in the 1% and 5% fortified samples.

The control and all other fortified samples had higher total phenolic content than the commercial sample. The commercial sample is a dairy product with no enrichment or fortification whatsoever. On the other hand, the other samples are of non-dairy origin and were fortified with *Moringa*.

Table 6. The Oxygen Radical Absorbance Capacity (ORAC) and Total Phenolic Content (TPC) results of Amasi

Sample	ORAC (umol TE/L)	TPC (mg/GEA/L)
Control	962.39 ± 171.15[a]	97.18 ± 3.85[a]
1% MOLP	6379.10 ± 107.87[b]	397.44 ± 9.40[b]
5% MOLP	15488.06 ± 248.25[ab]	1234.87 ± 14.84[ab]
Unfermented	1213.79 ± 33.86[c]	148.72 ± 1.54[c]
Commercial	1148 ± 62.73[bc]	170.7667 ± 18.50[bc]

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns indicate a significant difference (p ≤ 0.05).

3.3.2 Antioxidant Activity of Sorghum *Mageu*

As shown in Table 7, a significant difference in the ORAC values was observed for all samples. The unfermented sample showed significantly higher ORAC values than the unmalted control and 5% samples; however, the unmalted 1% sample showed higher ORAC values than the malted 1% sample. Other work has also reported increased in total phenols, tannins, total leucoanthocyanin, and total anthocyanin in four Sorghum cultivars germinating for up to 96 hours (36). Increasing levels of MoLP caused a significant increase in ORAC values in both the malted and

Table 7. Antioxidant activity of sorghum *Mageu*

Samples	ORAC umol TE/l	Polyphenols (mg/ GAE/L)
Unmalted Control	835.66±33.50^{a}	38.97±2.35^{a}
Unmalted unfermented	3961.66±109.00^{b}	72.31±13.32^{b}
Unmalted 5%	4981.67±190.31^{c}	245.36±11.95^{c}
Malted Control	6365.33±292.50^{d}	234.36±3.87^{c}
Malted 1%	11188.00±183.00^{e}	906.67±16.95^{d}
Malted unfermented	11940.00±67.27^{f}	332.31±8.14^{e}
Unmalted 1%	14114.00±487.50^{g}	468.72±12.43^{f}
Malted 5%	14824.31±306.00^{h}	933.85±17.75^{g}

Values are mean ±standard deviation. Different superscripts in columns represent a significant difference (p ≤0.05). Oxygen Radical Absorbance capacity (ORAC)

unmalted samples. The only exception is the unmalted 5% sample, which again has values lower than the unmalted 1% sample. According to a study (37), *M. oleifera* exhibits high antioxidant activity. Additionally, it has been reported that MoLP can be used as an antioxidant source in foods (38). The malted control values for ORAC were significantly higher than the unmalted fermented control values of 835.66±33.50 umol TE/L. According to a study performed (39), one white Sorghum variety was reported to have ORAC values of 868 umol/TE/L. The significant increase in the ORAC values of the fermented unmalted sample would suggest that fermentation decreased the antioxidant activity. According to a study (40), it appears that, unlike malting, fermentation reduces the levels of phenolics in Sorghum and millets (6).

The TPC values present similar trends to the results reported for ORAC values. All samples have TPC values that are significantly different except for the unmalted 5% and the malted control. The unfermented unmalted control values of 72.31±13.32mg/GA/L were significantly higher than the 38.97±2.35 mg/GAE/L found in the unmalted fermented control suggests fermentation reduced the total phenolics in the *Mageu*. According to Taylor (40), fermentation may reduce the extractability of phenolic compounds due to self-polymerisation or interaction with macromolecules such as proteins. The malted 0%, 1%, and 5% samples all show significantly higher TPC values than the corresponding levels in the unmalted samples. A previous study also demonstrated an 87% increase in the total phenolic content of selected sorghum cultivars upon malting (41). Increasing levels of MoLP cause significant increases in TPC in both the malted and unmalted samples. The only exception is the unmalted 5% sample, which again has values lower than the unmalted 1% sample as above for ORAC. The ORAC and TPC values for the unmalted 5% samples are far lower than expected. The unmalted 5% sample does not give us the desired results. Perhaps this sample was compromised during storage and before analysis. The data shows a correlation between TPC and ORAC values. This indicates that the phenolics contribute to the radical scavenging activity of the sorghum *Mageu*.

3.4 The rheological properties of Amasi and Mageu

3.4.1 The rheological properties of Amasi

The QC rheolab equipment measured rheology in three key aspects, tabulated below. These are shear stress, viscosity, and torque. *Moringa* had a significant ($p \leq 0.05$) effect on the stress properties of the samples in Table 8. According to the results, the shear stress of unfermented BGN milk had the lowest shear stress compared to the rest of the samples. This made sense considering the concept of fermentation, which in many liquids results in increased viscosity and the observed physical attributes of the fermented and commercial samples. All the samples had a thicker viscosity compared to the unfermented samples. The unfermented milk had a thin viscosity compared to the fermented and commercial samples. The amount of shear stress applied to a runny liquid and a thicker liquid varies, and the denser liquid requires more shear stress than the runny or less dense liquid (26). The commercial sample had the thickest viscosity among all the samples, and its shear stress was significant compared to the rest of the samples ($p \leq 0.05$); hence, Table 8 shows that it had the highest shear stress. There are many possible reasons for this; one is that it is of dairy origin. It could also be that its fermentation process was carried out over a long time than the fermentation on this project, and also it could be that more than one starter culture was used to ferment the product. The shear stress increased as the fortification percentage increased from 1 - 5%. This made sense because as more *Moringa* was added to the BGN milk, the viscosity increased, which then led to increased shear stress and according to literature, this was because the amylose content in the BGN significantly influenced the viscosity within the studied shear rate range of 10 and 1000 s^{-1} (26). The trend observed in the shear stress results had the same pattern as in the viscosity readings.

The *Moringa* had a significant difference ($p \leq 0.05$) in the viscosity of the fortified samples, considering the directly proportional relationship between viscosity and shear stress. The viscosity tabulated in Table 8 below showed an increase from 0% to 5% in *Moringa* fortification. The observed physical attributes were that as *Moringa* was added to the BGN milk, the thickness increased from 0% to 5%. It was more difficult to dissolve the *Moringa* at 5% than at 1%. This trend was also understood to make sense

Table 8. The effect of *Moringa* on the rheological properties of *Amasi*

Sample	Shear Stress (Pa)	Viscosity (mPa.s)	Torque (mN.m)
0%	2.033 ± 0.21^{a}	4.06 ± 0.43^{a}	0.10 ± 0.01^{a}
1%	2.94 ± 0.22^{b}	5.88 ± 0.44^{b}	0.16 ± 0.01^{b}
5%	4.82 ± 0.20^{ab}	9.62 ± 0.40^{ab}	0.26 ± 0.01^{ab}
unfermented	1.6917 ± 0.02^{a}	3.38 ± 0.04^{a}	0.09 ± 0^{a}
Commercial	40.06 ± 7.06^{c}	80.13 ± 14.12^{c}	2.13 ± 0.37^{c}

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns indicate a significant difference (p≤ 0.05).

through the moisture content concept. The moisture content decreases as one adds more powder substance to a liquid.

The peak viscosity of Bambara groundnut starch has been reported in different units (42). The peak viscosity values may be explained by differences in starch composition, e.g., amylose contents (42). However, the latest studies on Bambara groundnut starch found no inverse correlation between peak viscosity with amylose contents (42). Hence, other factors include trace amounts of lipid complexed amylose chains, the strong interaction between amylose-amylose or amylose-amylopectin chains, and the molecular structure of amylose and amylopectin may influence the peak viscosity of Bambara groundnut starch (10). All the BGN milk had the same moisture content before adding *Moringa*. Like any other liquid with high moisture content, adding powder will tend to decrease the moisture content. The moisture content will be lowered when the MoLP is added more, increasing the viscosity of the liquid. The commercial sample had the highest viscosity compared to all the samples. The reasoning is the same as explained in the previous subsection. Torque is a twisting or turning force that tends to cause rotation around an axis, which might be a centre of mass or a fixed point. Again, *Moringa* had a significant ($p \leq 0.05$) effect on the torque of the samples in Table 8. The torque readings increased from the unfermented sample to the 5% *Moringa* fortified sample. This was expected considering that the viscosity or thickness of the samples after fermentation increased from unfermented to 5% *Moringa* fortified sample and the relationship between torque and viscosity. Viscosity is directly proportional to the torque; thus, as viscosity increases, so does torque.

3.4.2 The rheological properties of Mageu

As shown in Table 9 below, all the samples exhibited decreasing viscosity and shear stress, except Unmalted 1%, where the viscosity and shear stress did not change much, and the final results were slightly higher than the initial results for viscosity and shear stress. The samples vary significantly in their shear stress and viscosity values over time. However, they all follow a similar flow—initially, a steep drop in shear stress and viscosity followed by a more gradual decline. Shear stress and viscosity run almost parallel over time, indicating that shear stress and viscosity are somewhat proportional. An increase in shear stress is, therefore, indicative of an increase in the viscosity of the product and vice versa. Each sample shows very different initial and final values for shear stress and viscosity. Both 5% enriched samples have the highest values for shear stress and viscosity in the fermented samples. Fermentation time increases due to an increase in fat, protein, and crude fiber during fermentation, which increases viscosity. However, malting alone led to a reduction in product viscosity. However, the malted samples show lower initial and final viscosity than the unmalted samples (43). This indicates that fermentation should result in an increase in viscosity, which is contradictory to our results. According to the previous study, unfermented beverages showed uneven texture, with phase separation occurring soon after mixing (44). This could mean the Sorghum samples were not homogenous, possibly resulting in the viscometer measuring a very dense sample area in the cup. Shear stress and viscosity decreased over time at a constant shear rate, indicating shear thinning behaviour in all the samples.

Table 9. The effect of *Moringa* on the rheological properties of *Mageu*

Sample	Shear Stress (Pa)	Viscosity (mPa.s)	Torque (mN.m)
Malted 5%	2.00±0.17	4.00±1.99	0.11±0.05
Unmalted 5%	2.23±0.19	4.46±0.39	0.12±0.01
Unmalted 1%	2.46±0.10	4.93±2.39	0.13±0.06
Malted 1%	3.56±0.57	7.12±0.20	0.19±0.01
Malted Unfermented	4.11±0.99	8.23±0.35	0.22±0.01
Malted Control	4.88±1.19	9.77±1.14	0.26±0.03
Unmalted Unfermented	116.66±16.90	233.32±33.81	6.22±0.88
Unmalted Control	118.98±20.48	237.99±100.81	6.36±2.69

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns indicate a significant difference ($p \leq 0.05$).

3.5 Titratable acidity of Amasi

Table 10 below shows the titratable acidity of *Amasi* and the commercial product. The observed trend was that control had the highest titratable acidity of all the samples, whereas 5% had the lowest reading of the other samples. Since titratable acidity measures the amount of acid produced in a solution, this means that the control sample produced more acid than the other samples. In contrast, the 5% produced the least amount of acid. The reason for this could be that the presence of *Moringa* at high concentrations decreased the amount of acid the microorganisms produced to ferment the milk. There was little difference between the 1% sample and the acid generated. There was no significant effect ($p \geq 0.05$). The reason for this could not be found in the literature. The possibility, however, is that the inclusion of *Moringa* reduces the amount of acid produced (14).

Table 10. The titratable acidity of fortified *Amasi*

Sample	Titratable acidity (g/L)
Control	0.62 ± 0.10^{a}
1% MoLP	0.57 ± 0.12^{a}
5% MoLP	0.45 ± 0.20^{ab}
Commercial	0.50 ± 0.19^{bc}

[1]Values are means ± Standard Deviation (S.D.). Different superscripts in columns indicate a significant difference ($p \leq 0.05$).

Conclusion

At 5% inclusion, MoLP-enriched *Amasi* and *Mageu* had more nutrients, such as protein and minerals, than unfortified (control) Bambara groundnut milk (*Amasi*) and Sorghum *Mageu*. This shows that MoLP is valuable for enhancing the nutritional content of *Amasi* and *Mageu* to help populations that depend on Bambara groundnut and Sorghum as essential staples to address nutrient deficits.

Authors' contributions

AF wrote most of the abstract, introduction, result, discussion, and conclusion. AN participated in the bench work, materials, and methods. EN wrote the materials and methods, and OO wrote the results and discussion of the manuscript. OO participated in the design and coordination of the manuscript. The statistical analysis and finalisation of the manuscript was done by AO.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None

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