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Investigating the probiotic potential and starch digestibility of pearl millet traditional ogi-porridge and wholegrain ogi-porridge prepared with starter culture

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Abstract
Ogi-porridge is a breakfast cereal frequently consumed in sub-Saharan Africa. It is prepared from a sour starch cake obtained by fermenting cereals grains. As a breakfast meal, some nutritional requirements which ogi-porridge could meet that will be of health benefit are probiotic microbes, fiber, and good starch digestibility. Here we analyzed the possibility of pearl millet ogi-porridge as a probiotic food by employing starter cultures. We followed the starch digestibility of modified ogi-porridge made from pearl millet wholegrain flour. Our findings reveal residual lactic acid bacteria of up to 10^3 cfu/ml for traditional ogi-porridge and 10^4 cfu/ml for modified ogi-porridge. Starch content was 77.90 and 66.10, while protein content was 9.82 and 12.00, respectively. Interestingly, the starch digestibility of modified ogi porridge was higher than that of traditional ogi-porridge, though both were significantly lower than that of refined wheat bread. This study shows that acceptable wholegrain ogi-porridge can be made from pearl millet grain and that if ogi-porridge is prepared using an appropriate temperature-time combination could contain residual live beneficial microbes.

Keywords: Ogi, pearl millet, fermentation, starter culture, probiotic food

Introduction

Ogi is a sour starch cake made from fermented cereal grains and serves as an intermediate for preparing various food products (Agati *et al*., 1998; Onyekwere *et al*., 2004) [6, 26]. Common cereal grains used for ogi production are maize, millet, and sorghum (Osungbaro, 2009) [27]. The food products made from ogi are a gruel that serves as complementary infant food, a spoon-able porridge named akamu, a non-alcoholic beverage known as kunu, and a dumpling locally called agidi. In reality, the total soluble solids (TSS) content of ogi paste and the temperature-time combination used in preparing these ogi products affect their final viscosities and distinguish an ogi product from the other.

Cooking a 15% TSS ogi paste for 15-20 min, followed by cooling, which allows the cooked paste to set, yields the dumpling referred to as agidi (Osungbaro, 2009) [27]. Meanwhile, adding boiling water to ogi paste or bringing an ogi slurry of slightly 6% TSS content to a boil yields a spoon-able porridge similar to a Greek-style yogurt in consistency. Reducing the viscosity of this spoon-able porridge to a drinkable liquid turns it into a weaning gruel. Adding spices such as ginger and black pepper to this gruel transforms it into a refreshing non-alcoholic beverage named kunu (Onyekwere *et al*., 2004) [26].

Both ogi and its liquor, the liquid that separates from the starch cake (ogi) during fermentation, are often taken to relieve intestinal discomforts and diarrhea (Aderiye and Laleye, 2003; Adebukunola *et al*., 2015) [2, 5]. Studies have shown that ogi can prevent the proliferation of human pathogenic bacteria such as *Shigella dysenteriae*, *Salmonella typhi*, *Escherichia coli*, and *Staphylococcus aureus* (Adebolu *et al*., 2007; Aderiye and David, 2013a; Aderiye and David, 2013b) [1, 3, 4], due to the probiotic potential of some of the LAB species such as *L. plantarum* and *L. fermentum*, associated with ogi (Parvez *et al*., 2006) [30].

Probiotics are preparations containing live defined microorganisms in sufficient numbers, which alter the host's microflora and exert beneficial health effects on this host (Schrezenmeir and De Vrese, 2001) [35]. They exert health benefits by producing antimicrobial substances that fight against pathogenic microorganisms, inhibiting bacterial enzymes that convert procarcinogens to proximate carcinogens in the gut and affecting the expression of genes involved in immune response (Nagpal et al., 2012; Hernandez and Pandiella, 2014) [21, 16]. The ability to withstand the low pH and bile concentration in the human gastrointestinal tract and to compete for adhesion sites enable probiotics to affect health positively (Hernandez and Pandiella, 2014) [16].

Since some lactic acid bacteria (LAB) and yeast associated with ogi possess probiotic features, it would be interesting to find out if the temperature-time combination in preparing ogi-porridge would allow ogi-porridge to serve as a probiotic food. To approve a food as a probiotic, it should contain a minimum of 10^6 cfu/ml of live probiotic microorganisms during consumption (Hernandez and Pandiella, 2014) [16].

As a high-carbohydrate food, the starch digestibility of ogi-porridge is of nutritional interest. Starch is the main glycemic carbohydrate, and its digestibility is related to the increasing incidence of obesity and diet-related diseases (Wang and Copeland, 2013) [41]. How rapidly starch is digested during in vitro digestion by amylases is valuable information in predicting the glucose-raising potential of starchy foods. Slowly digested starch (digested within 20 min and 120 min) and resistant starch (undigested after 120 min) are considered desirable in mitigating risk factors for diet-related diseases (Wang and Copeland, 2013) [41]. Thus, a healthy lifestyle favors the consumption of wholegrain foods above refined grain foods because of their dietary fiber content and higher carbohydrate quality (more slowly digested and resistant starch content). However, the intake of wholegrain products globally is lower than the general recommendation (Tieri *et al*., 2020) [39].

Pearl millet is an annual grass and the most cultivated type of millet (Shahidi and Chandrasekara, 2013) [36]. Its germ and bran are rich in protein and minerals (Hoseney, 1988) [17]. However, most traditional methods of preparing pearl millet lead to a significant loss of bran and germ nutrients (Muller, 1970; El Hag *et al*., 2002) [20, 13].

In this study, pearl millet wholegrain flour was fermented with a starter culture (*Lactobacillus plantarum* and *Saccharomyces cerevisiae*) and used to prepare an ogi-porridge. The probiotic potential and starch digestibility were carried out on the ogi-porridge and compared to the traditionally prepared ogi-porridge.

Materials and Method

Collection of materials

Pearl millet grains were purchased from a local market in southeastern Nigeria and cleaned to remove extraneous matter. *Lactobacillus plantarum* A203 was isolated from pearl millet in the Department of Food and Environmental Science, University of Helsinki, Finland. *Saccharomyces cerevisiae* H10 was purchased from the HAMBI culture collection, University of Helsinki, Finland.

Inoculum/starter culture preparation

Starter cultures were propagated in appropriate media before inoculation. *Lactobacillus plantarum* A203 was grown in DeMan Rogosa and Sharpe (MRS) broth (LAB M Ltd LAB0904, Lancashire, United Kingdom) at 30ºC, while *Saccharomyces cerevisiae* H10 was grown in yeast broth at 22ºC. Yeast broth (YM) contained 3 g/L of yeast extract (MC001, LAB M Ltd), 3 g/L of malt extract (MC023, LAB M Ltd), 5 g/L of soy peptone (MC003, LAB M Ltd), and 10 g/L of glucose (D (+)-Glucose Analar Normapur, VWR Pennsylvania USA).

Ogi and ogi-porridge preparation

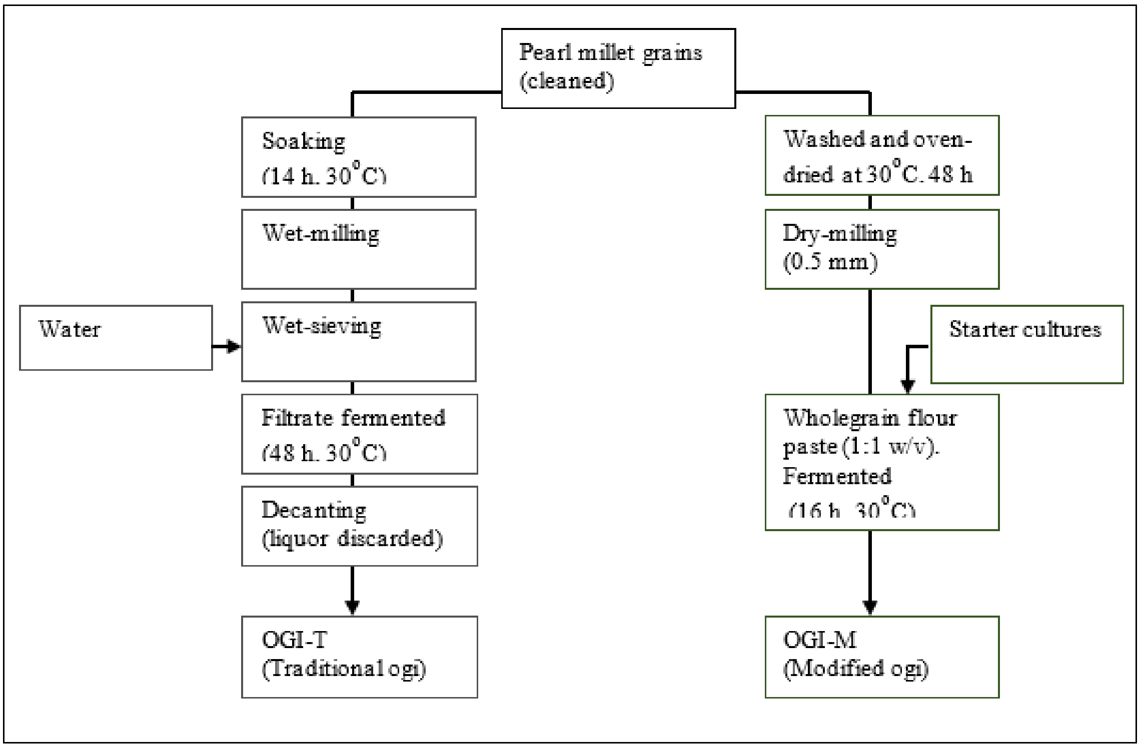

Fig 1: Traditional and modified methods of ogi production.

Traditional ogi

Traditional ogi were prepared in triplicate, using the method described by Akingbala *et al*. (1981b) [7] with slight modification, as shown in figure 1. For each sample of traditional ogi, 300 g of pearl millet grains were soaked in 600 ml of distilled water for 14 h at 30ºC. Afterward, the soaked grains were washed twice with distilled water and wet-milled with Janke and Kunkel Ultra Turrax homogenizer four times (10 min for each stage, at 20 500 rpm). After each milling stage, the milled mash was washed (wet-sieved) with distilled water. A total of 810 ml of distilled water was used to wet-mill the soaked grains and 900 ml of distilled water for washing the wet-milled mash. The filtrate obtained after wet-sieving was spontaneously fermented at 30ºC for 48 h and decanted to recover traditional ogi.

Modified Ogi

Modified ogi was prepared in triplicate using the method outlined by Akingbala *et al*. (2002) [8], with some modifications (figure 1). Pearl millet grains were washed with distilled water, oven-dried (Memmert GmbH oven, Schwabach, Germany) at 30ºC for 48 h, and milled to 0.5 mm particle size wholegrain flour with Retsch ZM 200 centrifuge mill.

Before inoculation, cells were cultivated until the late exponential phase of growth, corresponding to 24 h at 30ºC in the case of *L. plantarum* A203 and 29 h at room temperature (22-23ºC) in the case of *S. cerevisiae* H10. Afterward, cell pellets were recovered by centrifugation (Thermo Fisher Scientific Heraeus Pico 17 microcentrifuge, Massachusetts, USA) at 10 000 rpm for 10 min and washed with 20 mM phosphate buffer, pH 7.0. Then, 400 g wholegrain flour paste (200 g pearl millet wholegrain flour, 195 ml distilled water, and 5 ml cell suspension of *L. plantarum* A203 and *S. cerevisiae* H10) at an initial cell density of 10^6 cfu/ml *L. plantarum* and 10^5 cfu/ml *S. cerevisiae*. After 16 h of fermentation at 30ºC, the sourdough referred to as modified ogi was obtained.

Ogi-porridge preparation

Ogi-porridges were prepared by adding 95 ml of boiling (100ºC) distilled water to 40 g of each ogi (OGI-T and OGI-M) with minimal stirring. The porridges (OGI-TP and OGI-MP) were prepared in triplicates and allowed to cool to room temperature. Part of the ogi-porridges were freeze-dried (Heto Drywinner, Denmark) and stored at -20ºC for further analysis.

Preparation of samples for analysis

The grains were milled to wholegrain flour for all the analyses carried out on pearl millet grain (PMG). Ogi-porridges were freeze-dried.

Changes in acidity

The pH values were obtained using a portable hand pH meter (Foodcare HI 99161 Hanna Instruments, USA). Total titratable acid (TTA) was measured with an automated titrator (Mettler Toledo Easy Plus Titration, Mumbai, India). Distilled water (100 ml) was added to 10 g of sample and titrated against 0.1 N NaOH until pH 8.5 was attained, then TTA was recorded as the amount of 0.1 N NaOH required to achieve pH 8.5.

Enumeration of microorganisms

For microbial enumeration, 10 g of PMG, ogi, or ogi-porridge sample was serially diluted by blending (Oster 12-speed precise blend, Florida, USA) in 90 ml of 0.9% (w/v) sterile NaCl physiological solution for 30 seconds to 1 min. Dilutions were plated as follows: MRS agar (LAB0903, LAB M Ltd) was used for enumerating LAB, VRBGA - violet red bile glucose agar (LAB088, LAB M Ltd) was used for *Enterobacteriaceae*, and yeasts were enumerated on YM agar, which was prepared as stated previously, but with the addition of 15 g/L of agar (Agar No 1 MC002 LAB M Ltd), and 150 ppm chloramphenicol supplement (Oxoid Limited, Basingstoke Hampshire, United Kingdom) to inhibit bacterial growth. After incubation at 30ºC for 48 h (LAB), at 22-23ºC for 6 days (yeast), and *Enterobacteriaceae*, at 30ºC, 40ºC, and 4ºC for 48 h, the visible colonies were counted for each microbial group.

Starch content analysis

Starch content was analyzed with the Megazyme total starch kit (Megazyme International, Wicklow, Ireland). Freeze-dried ogi-porridge samples (OGI-TP and OGI-MP) or PMG (100 mg) were washed with 80% ethanol as the kit instructed. And sample pellets were recovered by centrifuging at 3000 rpm for 10 min (Hofstra-group Eppendorf 5810R refrigerated centrifuge, New Mexico, USA). Next, samples were hydrolyzed sequentially with α-amylase and amyloglucosidase enzymes. Then, the product of hydrolysis – glucose was recovered by centrifuging hydrolyzed samples at 3000 rpm for 10 min (Eppendorf 5810R refrigerated centrifuge). Finally, glucose was quantified with a spectrophotometer (Shimadzu UV-1800 UV-Vis Spectrophotometer, Maryland, USA) with the following steps: 1:100 diluted supernatant (obtained after centrifuging hydrolyzed sample) was mixed with 3 ml of GOPOD reagent, and incubated in a 50ºC water bath for 20 min, before reading absorbance at 510 nm.

Protein content analysis

The protein content of PMG, freeze-dried ogi-porridges (OGI-TP and OGI-MP) was determined by evaluating the total nitrogen contents using the Dumas combustion method (employing the Vario Max CN element analyzer, Elementar Analysensysteme GmbH, Germany) and afterward calculating protein content with appropriate conversion factor (5.83).

Starch digestibility

The method outlined by Germaine *et al*. (2008) [15] was implemented with slight modification. Freeze-dried ogi-porridge and PMG samples containing 1 g of starch were homogenized in 100 ml of 0.05 molL^{-1} sodium potassium phosphate buffer (pH 6.9), to which 110 U porcine pancreatic amylase (Type 1-A Sigma Chemical Company, Saint Louis, USA) was added. Then starch was hydrolyzed by incubating the enzyme-sample mixtures in a 37ºC water bath for 180 min, with constant shaking. Aliquots were taken at 0, 30, 90, 120, and 180 min, and placed in a boiling water bath for 5 min, to stop enzyme activity. These aliquots were maintained in ice until reducing sugar was analyzed.

For analyzing reducing sugar content, sample aliquots were centrifuged (Eppendorf 5810R refrigerated centrifuge) at 12 500 rpm for 5 min. The supernatants (1 ml) were mixed with 1.5 ml of 3,5-dinitrosalicyclic solution and placed in a boiling water bath for 5 min. Using Shimadzu UV-1800 UV-Vis spectrophotometer, absorbance was measured at 540 nm. The quantity of glucose was read off from a glucose standard curve of 0.1 gL^{-1} to 2.2 gL^{-1} using the absorbance values.

Sample preparation for sensory evaluation

Traditional and modified ogi-porridges were prepared by adding 95 ml of boiling (100ºC) distilled water to 40 g of each ogi (OGI-T and OGI-M), with minimal stirring.

Sensory evaluation panel

The sensory panel consisted of 35 untrained persons familiar with the traditional ogi-porridge. They evaluated ogi-porridge samples for color, aroma, mouth feel, sourness, and overall acceptability using a 7-point hedonic scale described by Epler *et al*. (1998) [14]. For color, aroma, and overall acceptability, 1 on the scale represents dislike extremely while 7 represents like extremely. For mouth feel, 1 represents rough, and 7 represents extremely smooth. For sourness, 1 illustrates not sour, and 7 illustrates extremely sour.

Statistical analysis

The analyses were carried out in triplicate, and the mean data ± SD (standard deviation) were reported. Analysis of variance (ANOVA) for repeated measurements was used to analyze the data. The parameters analyzed were compared between pearl millet grain, traditional ogi, modified ogi, and the ogi-porridges using a statistical package for the social sciences (SPSS) software. Significance was accepted at $p \leq 0.05$.

Results and Discussion

Microbiological and acidification properties.

The production of traditional ogi depended on natural fermentation. It took 48 h to achieve 10^8 cfu/ml of LAB, 10^5 cfu/ml of yeasts, and a 19.6% decrease in *Enterobacteriaceae* cell density (from 5.1 to 1.0 x 10^5 cfu/ml). Different microbial groups dominate in different stages during the natural fermentation of cereals. At the onset of fermentation, all microbial groups grow and increase in cell density. However, a few hours into fermentation, *Enterobacteriaceae* and molds gradually die off as LAB produces organic acids, which lower the pH of the medium, making the environment unfavorable for other groups of microorganisms (Omemu, 2011) [24]. A few yeasts that tolerate low pH levels remain, but LAB often dominates the environment (Salovaara, 2004; Omemu *et al*., 2007) [33, 2].

Using starter cultures during modified ogi production resulted in high initial LAB cell density (10^6 cfu/ml), which gave LAB an edge over the rest of the micro flora. LAB and yeast grew to 10^9 and 10^7 cfu/ml, respectively, while *Enterobacteriaceae* cell density reduced from 10^5 to 10^3 cfu/ml.

Table 1: Total titratable acid (TTA), pH, and microbial analysis of traditional ogi and ogi-porridge.

Samples	Fermentation time (h)	pH	TTA (ml)	LAB[a] (cfu/ml)	Yeast (cfu/ml)	*Enterobacteriaceae* (cfu/ml)
PMG	0	6.9 ±0.2	1.9 ±1.8	_	_	5.1 ± 6.6 x 10^5
OGI-T	48	3.9 ±0.1	8.0 ±1.5	3.6 ±1.6 x 10^8	1.7 ±2.3 x 10^5	1.0 ±0.4 x 10^5
OGI-TP		3.9 ±0.1	2.5 ±0.7	7.7 ±0.7 x 10^3	<10^2 ±0.6	<10^2

All values are means of three replicates.

PMG - Pearl millet grain; OGI-T - Traditional ogi; OGI-TP - Traditional ogi-porridge; LAB - Lactic acid bacteria.

Microbial safety of ogi is essential. Hence, the rapid growth of LAB is required during fermentation to ensure timely and sufficient production of metabolites (such as organic acids) that will halt the growth of pathogenic bacteria and eventually eliminate them (Akinrele, 1970; Leroy and De Vuyst, 2004) [9, 18]. With the rapid proliferation of LAB in OGI-M, 60% more TTA was obtained in only 16 h compared to traditional ogi after 48 h of fermentation. The higher TTA level in modified ogi strongly contributed to the significant reduction of *Enterobacteriaceae*. Most pathogenic bacteria such as *E. coli* and *Salmonella* sp. belong to the *Enterobacteriaceae* family (Penalver *et al*., 2005) [31]. Therefore, employing starter culture ensures microbiological safety while reducing the time involved in producing ogi, from days (often required for the traditional method) to only a few hours.

Table 2: Total titratable acid (TTA), pH, and microbial analysis of modified ogi and ogi-porridge.

Samples	Fermentation time (h)	pH	TTA (ml)	LAB[a] (cfu/ml)	Yeast (cfu/ml)	*Enterobacteriaceae* (cfu/ml)
OGI-M0	0	6.9 ±0.2	1.9 ±1.8	5.8 ±6.7 x 10^6	2.5 ±2.9 x 10^5	5.1 ± 6.6 x 10^5
OGI-M	16	3.9 ±0.0	12.8±0.3	4.1 ±0.4 x 10^9	2.0 ±0.6 x10^7	2.8 ±2.3 x 10^3
OGI-MP		3.9 ±0.2	4.1 ±0.1	5.9 ±5.2 x 10^4	$<10^2$ ± 0.0	$<10^2$

All values are means of three replicates.
OGI-M0 - Pearl millet wholegrain paste (1:1 w/v) inoculated with *L. plantarum* and *S. cerevisiae*; OGI-M - Modified ogi; OGI-MP - Modified ogi-porridge; LAB - Lactic acid bacteria.

Ogi-porridge can be prepared in two ways. One method involves cooking ogi slurry for about 3-5 minutes, often practiced in northern Nigeria. Preparing ogi-porridge with this method may not leave any surviving microorganisms. The other process of preparing ogi-porridge involves adding boiling water to ogi with minimal stirring and is generally practiced in southern Nigeria. With this method, up to 10^3-10^4 cfu/ml of LAB survived this cooking process (tables 1 and 2). However, this level of live LAB cells is lower than the minimum number (10^6 cfu) of viable probiotic microorganisms required to approve a food as a probiotic. An uncommon traditional practice of adding ogi to a ready-to-eat ogi-porridge before consumption, which is said to make ogi-porridge taste creamier, may increase the final amount of viable LAB. However, further studies on this possibility would be beneficial since the amount of ogi added to ready-to-eat ogi-porridge is often nearly as much as was used to prepare the ogi-porridge. And studies have shown that some *Lactobacillus* sp (particularly *L. plantarum*), *Pedicocccus* sp, and *Lactococcus* sp, isolated from ogi and kunu, possess probiotic qualities (Oyetayo and Osho, 2004; Oluwajoba *et al*., 2014; Oguntoyinbo and Narbad, 2015) [28, 23, 22].

Starch and protein content of ogi-porridges.

The traditional method increased starch content from 66.72% to 77.90%, while protein content decreased from 10.90% to 9.82% (table 3). Similar results were obtained with wet-sieving and dehulling of pearl millet (Akingbala *et al*., 2002; El hag *et al*., 2002) [8]. Pearl millet bran contains about 17% of the grain's total protein content (Hoseney, 1988) [17]. Discarding bran usually leads to the loss of an appreciable amount of nutrients. Hence, any unit operation resulting in bran loss concomitantly decreases the pearl millet's protein content.

The use of wholegrain flour for modified ogi retained the protein in pearl millet bran, contributing to modified ogi's higher protein content. Furthermore, fermenting with *Saccharomyces cerevisiae* may have contributed to the 10% increase in the protein content through their biomass. Fermenting cereals with *Saccharomyces cerevisiae* has been shown to increase protein content (Svanberg and Lorri, 1997; Yafetto *et al*., 2022) [38, 43].

Table 3: Starch and protein content of ogi porridges and pearl millet grain.

Samples	Starch content (% db)	Protein content (%)
PMG	66.72 ±1.26[b]	10.90 ±0.20[b]
OGI-TP	77.90 ±0.94[a]	9.82 ±0.32[c]
OGI-MP	66.10 ±1.18[b]	12.00 ±0.15[a]

All values are means of three replicates (except the predicted values). Means followed by the same letter in a column are not significantly different at $p<0.05$; (db) – dry basis.
PMG – Pearl millet grain; OGI-TP - Traditional ogi-porridge; OGI-MP - Modified ogi-porridge.

Starch digestibility of ogi-porridges.

Traditional and modified ogi-porridges did not differ significantly in their starch digestibility, but their values were substantially lower than white wheat bread (fig 2). The extent of starch gelatinization obtained while preparing the porridges may have contributed to the lower starch digestibility of the porridges. In this study, ogi-porridge was prepared by adding boiling water (100°C) to ogi. This method does not allow extensive starch gelatinization as often obtained in bread baking. Wootton and Chaudhry (1980) [42] observed that in vitro starch digestibility of wheat-based products is affected by the degree of starch gelatinization obtained during preparation. They found that wheat-based products with a high degree of gelatinization (such as bread and cake) had higher in vitro starch digestibility than products with less gelatinization (like biscuits). Parada and Aguilera (2009) [29] observed a similar trend with potato starch subjected to varying cooking temperatures.

Interestingly starch digestibility of the modified ogi porridge was higher than that of traditional ogi-porridge. Similarly, the starch digestibility of fermented sorghum was higher than that of naturally fermented sorghum (Pranoto *et al*., 2013) [32]. The activity of both grains endogenous and microbial amylase hydrolyzes starch into oligosaccharides and monosaccharides during fermentation, which consequently increases starch digestibility (Akingbala *et al*., 2002) [8] and is confirmed by the higher initial glucose content of modified ogi-porridge. Additionally, fermentation leads to proteolysis of the protein matrix surrounding the starch granules. As a result, the starch granules are liberated from the protein matrix and readily digested by amylase, thereby increasing the digestibility of the starch (Pranoto *et al*., 2013) [32].

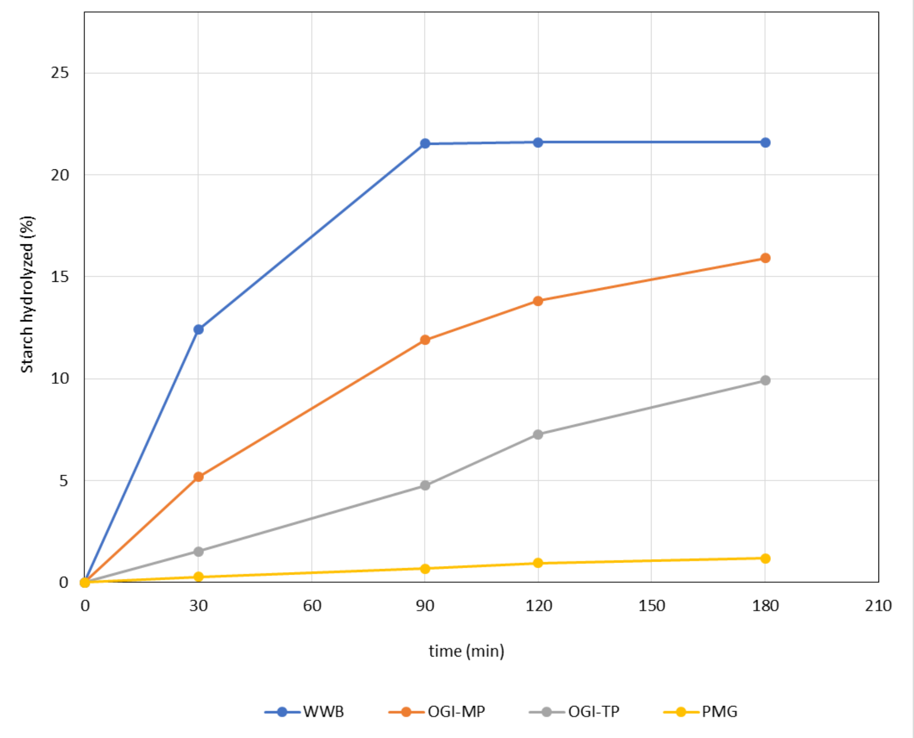

Fig 2: Percentage of **s**tarch hydrolyzed in pearl millet grain (PMG), traditional ogi-porridge (OGI-TP), modified ogi-porridge (OGI-MP), and white wheat bread (WWB) at varying time intervals.

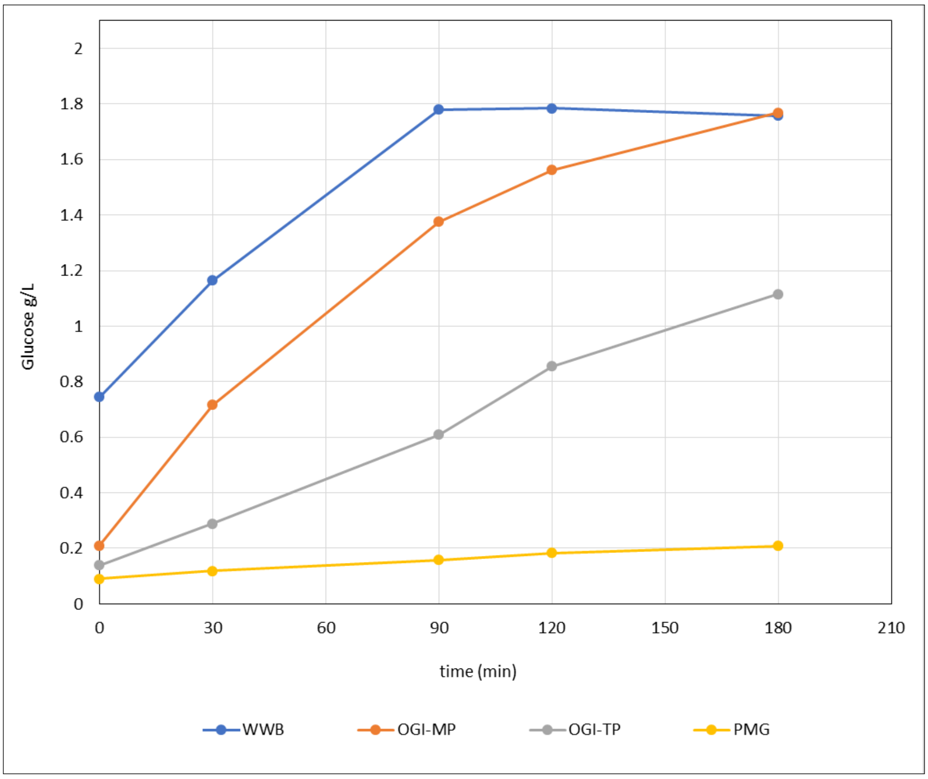

Fig 3: The amount of glucose released in pearl millet grain (PMG), traditional ogi-porridge (OGI-TP), modified ogi-porridge (OGI-MP), and white wheat bread (WWB) at varying time intervals.

Furthermore, starch damage enhances starch digestibility due to the increased swelling power of damaged starch in water, which enhances enzyme accessibility (Dhital *et al*., 2010) [12]. In the wet-milling process, soaking grains in water before milling loosens the structure of starch, resulting in little or no starch damage (Chiang and Yeh, 2002) [11]. This process reduced starch damage in pearl millet and rice grains (Beleia *et al*., 1980; Chiang and Yeh, 2002) [10, 11]. Meanwhile, unlike wet-milling, dry-milling produces higher amounts of damaged starch

(Uriyapongson and Rayas-Duarte, 1994; Suksomboon and Naivikul, 2006) [40, 37] which are more susceptible to starch enzyme digestion.

Sensory evaluation of ogi-porridges.

Using wholegrain flour for modified ogi production yielded a slightly darker porridge than traditional porridge (figure 4). Modified ogi-porridge also had a stronger sour taste and aroma than traditional ogi-porridge because of its higher titratable acid content. However, for overall acceptability, it was still rated above average even without a sweetener.

Table 4: Sensory evaluation of ogi-porridges.

Samples	Colour	Aroma	Mouthfeel	Sour	Overall acceptability
OGI-TP	5.2^{a}	5.1^{a}	5.6^{a}	3.2^{a}	5.4^{a}
OGI-MP	4.0^{b}	3.8^{b}	4.4^{b}	4.1^{b}	4.0^{b}

Means followed by the same letter in a column are not significantly different at $p<0.05$.
OGI-TP - Traditional ogi-porridge; OGI-MP - Modified ogi-porridge.

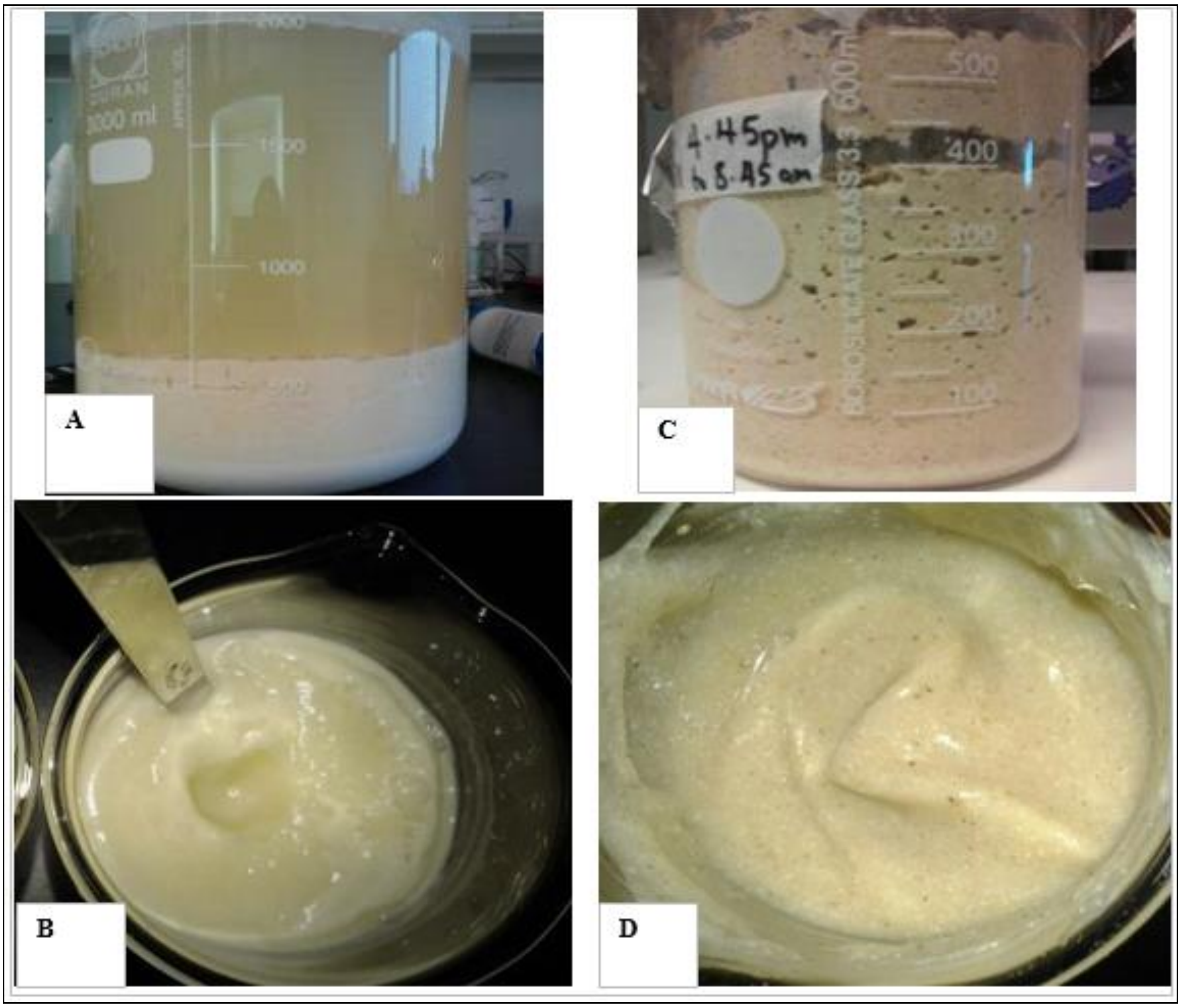

Fig 4: Pictures of ogi and ogi-porridge prepared in this study. A - Traditional ogi (the sediment); B – Traditional ogi-porridge; C – Modified ogi; D - Modified ogi-porridge.

Conclusion

Though the minimum number of viable probiotic microorganisms required to approve a food as a probiotic is 10^6 cfu, it is recommended to prepare ogi-porridge by adding boiling water to ogi, with minimal stirring because up to 10^3-10^4 cfu/ml of LAB survive the cooking process. The higher starch digestibility obtained with *L. plantarum* and *S. cerevisiae* fermentation and the higher protein content compared to natural fermentation allows the recommendation of processing wholegrain flour with this starter culture combination for products based on pearl millet flour, such as cookies, cake, and noodle with better nutritional quality.

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