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Combined Effect of Extrusion Cooking and Hydrocolloids on Senegalese Rolled Millet Flour ("Arraw") from *Pennisetum glaucum L. R. Br*

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Abstract

Senegalese rolled flour, known as "Arraw", is popular but has a long cooking time of 37 minutes. This study aimed to significantly reduce the cooking time by combining extrusion technology with binding agents (Arabic gum and maltodextrin) in various formulations. These formulations included EMAG7 (93% extruded millet + 7% Arabic gum), EMAG9 (91% extruded millet + 9% Arabic gum), EMMD11 (89% extruded millet + 11% maltodextrin), EMMD13 (87% extruded millet + 13% maltodextrin), and TrM traditional "Arraw" (100% non-extruded millet, as a control). The results showed total granule yields of 56% for EMAG7, EMAG9, and EMMD13, and 63% for EMMD11, compared to 70% for TrM (100%). Water absorption indices ranged from 3.57 to 4.56 g/g for the new formulations, compared to 1.04 g/g for TrM (100% millet) and 6.63 g/g for extruded millet flour (EM). Meanwhile, water solubility indices ranged from 11.31% to 15.24% for the new formulations, compared to 5.17% for TrM (100% millet) and 12.75% for EM. Cooking times ranged from 6 to 12 minutes for the new formulations, compared to 23 to 33 minutes for TrM (100% millet). Arabic gum and maltodextrin were excellent binders for extruded flour rolling. Maltodextrin significantly improved the solubility of precooked millet granules. This research demonstrates the potential of cooking extrusion in reducing cooking time while increasing water absorption and solubility of precooked rolled millet flour with relatively low porridge viscosity.

Keywords

Millet Flour Granules, Extrusion Cooking, Maltodextrin, Arabic Gum, Cooking Time

1. Introduction

Various traditional foods (bread, snacks, porridge) are made from millet, a common dietary staple in many parts of Africa and Asia [1]. In Senegal, thick and thin porridges are prepared from rolled decupled millet flour with granules of 2.5 or 3.5 mm. This product, traditionally known as "Arraw", takes around 37 minutes to cook [2]. Due to the long cooking time, it remains less popular among households despite its cultural significance. Additionally, some women processors in small and medium-sized enterprises have suggested that reducing the cooking time of "Arraw" could increase its market competitiveness. As a result, there is increasing interest in finding new techniques to shorten cooking times.

Few studies have explored techniques to reduce the cooking time of millet rolled flours, such as "Arraw". One study succeeded in reducing the cooking time for 2-mm millet flour granules from 37 to 9 minutes by incorporating 5 to 10% malted millet flour [3]. In addition to malting, extrusion cooking offers several advantages over other agricultural product processing methods. The extrusion process is a high-temperature, short time (HTST) process in which moist, starchy foodstuffs are plasticized and cooked in a barrel equipped with one or two screws [4]. According to [5], extrusion cooking produces food that is ready to eat while retaining its nutritional and sensory characteristics. However, extruded millet flour lacks the technological aptitude for rolling due to changes in the functional properties of the starch after extrusion. During extrusion, high shear forces disrupt the starch granules, drastic pressure changes result in the loss of native starch crystallinity, plasticization, and expansion of the food structure. This leads to reduced dough viscosity, loss of water retention, increased reconstitutability of the extrudates, softer product texture, and color changes [6].

Given these challenges, there is interest in using hydrocolloids to roll extruded flour. Hydrocolloids are a class of food ingredients widely used to develop food structure. They are primarily used for two reasons: their physical functionality and their nutritional benefits. Physical functionality typically involves adding viscosity or gelation to a food system. However, hydrocolloids can also help develop structure, modify texture, and extend shelf life. When used in this context, they are often referred to as "stabilizers". Many hydrocolloids are available for the food industry, including pectin, modified starches, modified celluloses, guar gum, locust bean gum, and konjac mannan. Gums such as Arabic gum are also commonly used in food processing. Furthermore, hydrocolloids can introduce natural fibers into the product, which offer benefits for gut microbiota. Gatthi gum and tragacanth gum are also hydrocolloids [7].

The aim of this study is to develop a new method for preparing millet flour granules that will reduce their cooking time. Specifically, the objective is to examine the impact of texturizing agents, namely Arabic gum and maltodextrin, on the production of granules from extruded millet flour and to assess their functional quality. The choice of these hydrocolloids is based on their accessibility and suitability for technology transfer. Furthermore, the hydrocolloids used in this study are already produced by an industry called "Valdafrique".

2. Materials and Methods

2.1. Plant Material

The plant materials used in this study included millet grains (*Pennisetum glaucum*), Arabic gum powder, and maltodextrin with a dextrose equivalent of 17.9. The millet grains were obtained from Free Work Services, while the Arabic gum powder was sourced from "Valdafrique" at "Laboratoires Canonne". The maltodextrin used in this study was manufactured by SENALIM.

2.2. Preparation of Extruded Millet Flour

Extruded millet flour was produced by cooking-extrusion at 26% humidity and a temperature range of 110˚C - 120˚C using a Technochem model single-screw mini-extruder, running at a screw speed of 900 rpm, with a die opening diameter of 6 mm. The feed rate was applied manually, as the screw feeder conveyor was inadequate for the extruder. The extruder was equipped with a 5514.7 W electric motor and a 220 V variable frequency drive. The millet grains were cleaned, sorted, and graded using traditional sieves. They were then dehulled and dry-crushed using a hammer mill fitted with a 4 mm mesh sieve to achieve a coarse particle size suitable for extrusion cooking. The extrudates obtained were dried at 50°C in an "Ouragan" oven for 4 hours. The dried extrudates were then passed through a hammer mill fitted with a 1 mm mesh sieve, and the resulting powder was collected as the extruded millet flour.

2.3. Development of Pre-Cooked Rolled Millet Flour Formulations

Pre-cooked "Arraw" formulations were prepared from extruded millet flour (EM) by adding either Arabic gum (AG) or maltodextrin (MD). Four distinct formulations were obtained: EMAG7 (93% extruded millet flour + 7% Arabic gum), EMAG9 (91% extruded millet flour + 9% Arabic gum), EMMD11 (89% extruded millet flour + 11% maltodextrin), and EMMD13 (87% extruded millet flour + 13% maltodextrin). Rolled hulled millet flour (TrM) was used as the control formulation. These formulations are summarized in **Table 1**.

The millet flour was rolled in the traditional way using an aluminum calabash. To facilitate rolling, the mixture was first moistened and rolled for pre-granulation. The granules formed were then calibrated using a 4 mm mesh sieve and dried at 50˚C in an Ouragan oven for 4 hours. The yield of dried pre-cooked granules is expressed as a function of 2 mm and 4 mm particle sizes.

$$Y_i = \frac{W_i}{W_t} * 100$$

Y_i: yield of dry, pre-cooked granules of size i;

W_i: weight of dry and pre-cooked granules of size i;

W_t: total weight of dry and pre-cooked granules.

Table 1. Formulations of different pellets from extruded millet flour and traditional hulled millet flour.

	Ratio of different flours in 100 g of rolled millet flour products			
Formulas	Dehulled millet flour	Extruded dehulled millet flour (EM)	Arabic gum (GA)	Maltodextrin (MD)
TrM	100	-	-	-
EMAG7	-	93	7	-
EMAG9	-	91	9	-
EMMD11	-	89	-	11
EMMD13	-	87	-	13

2.4. Water Absorption Index and Water Solubility Index of Millet Flour

The water absorption index (WAI) and water solubility index (WSI) of millet flours were determined using the method described by Rodríguez *et al.* [8] and later reported in other studies [9] [10]. For this, a portion of the "Arraw" was ground and sieved to obtain a particle size of 0.420 mm. A weight of 0.3 g (tested sample) of sieved powder was dispersed in 10 mL of distilled water and stirred gently for 30 minutes at 3000 rpm using a New Brunswick Scientific blender (Edison, NJ, USA). The resulting suspension was then centrifuged at 3000 G for 10 minutes using a Beckman Coulter centrifuge. The supernatant was collected in an evaporation dish, dried, and tared. The water was evaporated in an oven at 105˚C until a constant weight of the sample.

The following formulas in order to determine the WAI and WSI on related flours were used.

$$\text{WAI} = \frac{\text{weight of sediment or gel obtained after removal of supernatant}}{\text{weight of sample in dry matter}}$$

$$\text{WSI} = \frac{\text{weight of dry solids in supernatant}}{\text{weight of sample in dry matter}} * 100$$

2.5. Pasting Properties

The pasting properties of the flour were determined using the method described by [11]. Approximately 4 g of extruded millet flour (in powder form) was added to 25 mL of distilled water to obtain a 12% slurry dry matter. The test container was held at 50˚C for 1 minute, then heated from 50˚C to 95˚C at a constant rate of 12.16˚C/min. The sample was held at 95˚C for 2.5 minutes, then cooled back to

50˚C at a constant rate of 11.84˚C/min and held for an additional 2.5 minutes. The total cycle duration was 13 minutes, and the sample was mixed at a constant speed of 160 rpm throughout the process. The data collected from the Rapid Visco Analyzer (RVA) were analyzed using Thermocline version 1.2 software (Newport Scientific Pty. Ltd., Warriewood, Australia). All measurements were performed in triplicate.

2.6. Determination of Cooking Time

To evaluate the cooking time, 10 g of pre-cooked granules with a particle size of 4 mm were mixed with 80 mL of drinking water, while 20 g of pre-cooked granules with a particle size of 2 mm were mixed with 133 mL of drinking water. These quantities were determined after conducting several pre-tests to optimize the conditions for accurate cooking time assessment. The cooking time was measured using a stopwatch.

2.7. Statistical Analysis

As the number of formulated products represented sample sizes, three replicates were performed for each experiment. All data analyses were conducted using EXCEL and XLSTAT PRO software, version 6.1.9. Analysis of variance (ANOVA) was used to determine significant differences between the means, with a 95% confidence interval. Fisher's test was applied for post-hoc analysis.

3. Results

3.1. Granulation Yield

3.1.1. Millet Pellet Yields (Rolling) as a Function of Size

Figure 1 shows the yields of different millet pellet formulations based on particle size. Pellet yield was evaluated using two sieves with mesh sizes of 2 mm and 4 mm. The data indicate that formulations with rolled flour of 2 mm size provided higher yield granules than those with 4 mm granulometry. Specifically, the yields of 2 mm rolled flour granules range from 44% to 47% for the EMAG formulations and from 42% to 46% for the EMMD formulations. These yields are lower than that of the TrM control, which reached 63.33% of granule yield. As a result, the TrM control significantly differs from the four experimental formulations.

In contrast, the granule yields in 4 mm formulations range from 9% to 12% for EMAG and from 14% to 17% for EMMD. These yields are higher than that of TrM (7%), with EMMD11 showing the highest yield (17%).

3.1.2. Total Yields of Millet Pellets (Rolled Millet Flour)

Figure 2 shows the total yields of millet pellets. These yields were 56% for EMAG7, EMAG9, and EMMD13, and 63% for EMMD11. The TrM control had a yield of 70.3%, which was statistically higher than the four formulations mentioned above.

3.2. Water Absorption Index and Water Solubility Index

Table 2 shows the absorption and solubility of millet flour granules in water.

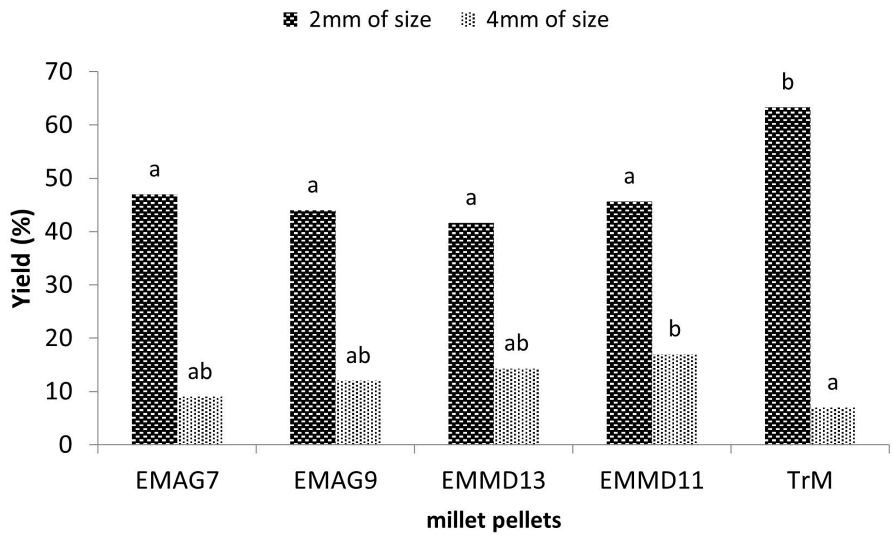

Figure 1. Millet pellet yields (rolling) as a function of diameter. For the same diameter, yields that are followed by the same letter are not significantly different at the 5% significance level.

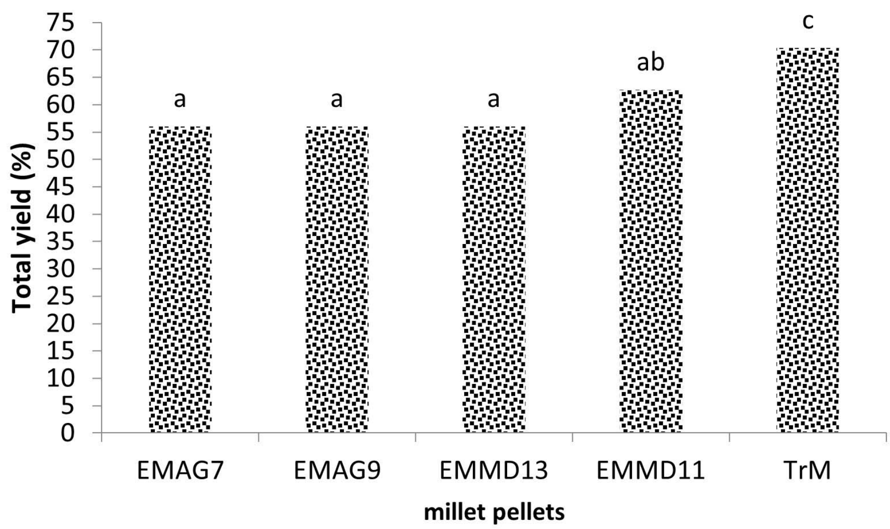

Figure 2. Total yields of different rolled millet flour samples. Yields followed by the same letter are not significantly different at the 5% level.

Water absorption indexes were 3.68 g/g dry matter and 4.56 g/g dry matter respectively for EMAG7 and EMAG9, compared to 3.57 g/g dry matter in EMMD. The extruded millet flour (EM) alone showed a water absorption index of 6.63 g/g dry matter, which was the highest. Meanwhile millet flour from the control (TrM) presented the lowest value of 1.04 g/g dry matter. The Fischer test shows that the latter is statistically weak compared with the water absorption indices of EMAG, EMMD and EM. It should be noted that EMAG9 has a water absorption index that is significantly higher than those of EMAG7, EMMD11 are and EMMD13 are but lower than that of EM.

Regarding the water solubility index, the values were 13.18%, 15.23%, 11.31%, and 11.71% respectively for EMMD11, EMMD13, EMAG7, and EMAG9 compared to 5.17% for the control, TrM. While for extruded millet flour (EM), the water solubility index found was 12.75%. These results showed that EMMD13 solubility index was significantly higher than the different formulations, including EM and TrM.

Table 2. Water Absorption Index (WAI) and Water Solubility Index (WSI) of different millet flours tested.

Rolled Millet Flour	Rolled Millet Flour (WSI)	Water Solubility Index (WAI)
TrM	1.04 ± 0.00a	5.17 ± 0.05a
EMAG7	3.68 ± 0.10b	11.71 ± 0.17b
EMAG9	4.56 ± 0.10c	11.31 ± 0.10b
EMMD11	3.57 ± 0.01b	13.18 ± 0.01c
EMMD13	3.57 ± 0.17b	15.23 ± 0.53d
Extruded Millet Flour (EM)	6.63 ± 0.18d	12.75 ± 0.14c

3.3. Pasting Properties

Pre-cooked millet flour samples from FEGA7, FEGA9, FEMD11, and FEMD13 showed maximum viscosities of 1060 mPa·s, 1002 mPa·s, 995.9 mPa·s, and 899.9 mPa·s, respectively, compared with 1149 mPa·s for TrM flour. The final viscosities of millet granule flours formulated with Arabic gum (AG) and maltodextrin (MD) ranged respectively from 180.1 to 185.9 mPa·s, and 188.6 to 198.2 mPa·s, compared to 1755 mPa·s for the control (TrM). In contrast, the degradation viscosity for TrM was recorded at 343.2 mPa·s, which is lower than that of the pre-cooked millet granules. The recoil viscosity of millet flour granules formulated with AG and MD provided respectively 96.9 to 100.5 mPa·s, and 108.3 to 114.7 mPa·s, both lower than the 949.2 mPa·s observed for the same control (TrM). Meanwhile the pasting temperatures of pre-cooked millet flour granules were found between 50.45 and 52.27 mPa·s, with no significant difference ($p > 0.05$). These pasting temperatures were all lower than the traditional millet flour (80 mPa·s) as the control. Meanwhile, extruded millet flour (EM) recorded maximum viscosity, final viscosity, degradation viscosity, and recoil viscosity values of 1014 mPa·s, 195.3 mPa·s, 930.1 mPa·s, and 111.4 mPa·s, respectively compared to previous values from other samples. However, its pasting temperature was 50.1 mPa·s, the lowest value found among all analyzed samples (**Table 3**).

3.4. Cooking Times

Figure 3 illustrates the average cooking time for millet granules of different sizes. The 4 mm granules were found to require a longer cooking time than the 2 mm granules across all formulations. Specifically, for the EMAG formulation, the cooking time ranged from 6 to 9 minutes for the 2 mm granules, whereas for the

Table 3. Pasting proprieties of the different rolled flour samples ("Arraw").

Rolled millet flour	Peak viscosity (mPa·s)	Breakdown viscosity (mPa·s)	Setback viscosity (mPa·s)	Final viscosity (mPa·s)	Pasting temperature (mPa.s)
EMAG7	1060 ± 3.31ab	974.6 ± 3.47c	100.5 ± 0.37a	185.9 ± 1.91a	51.4 ± 0.58a
EMAG9	1002 ± 3.53a	918.8 ± 3.38b	96.9 ± 2.58a	180.1 ± 4.10a	50.9 ± 0.00a
EMMD11	995.9 ± 3.64a	915.6 ± 3.31b	108.3 ± 1.00a	188.6 ± 6.79a	52.3 ± 0.64a
EMMD13	899.9 ± 4.52a	816.4 ± 4.56b	114.7 ± 0.32a	198.2 ± 0.07a	50.5 ± 0.64a
TrM	1149 ± 2.86c	343.2 ± 2.36a	949.2 ± 2.40b	1755 ± 1.90b	80 ± 1.28b
EM	1014 ± 0.12ab	930.1 ± 3.15bc	111.4 ± 0.07a	195.3 ± 0.53a	50.1 ± 0.23a

4 mm granules, they were slightly longer, ranging from 9 to 10 minutes. In comparison, the cooking time for the EMMD formulation varied from 6 to 7 minutes for the 2 mm granules compared to a variation of 11 to 12 minutes for the 4 mm granules. Statistically, the cooking times for EMMD granules were found to be significantly longer than for EMAG7 at the 2 mm size. However, at the 4 mm size, EMAG7 provided the longest cooking time and significantly greater than the ones for EMAG9, EMMD11, and EMMD13. This indicates that the size of the granules and the specific formulation both influenced the cooking time. In contrast, the TrM control cooking times of 22 minutes and 33 minutes respectively for 2 mm and 4 mm granules were found much significantly longer than the cooking times observed for any of the formulated ones. These results demonstrated that, regardless of the size, the TrM control consistently requires more time to cook than the formulated granules, highlighting a key difference in processing time between the TrM control and the millet formulations (**Figure 3**).

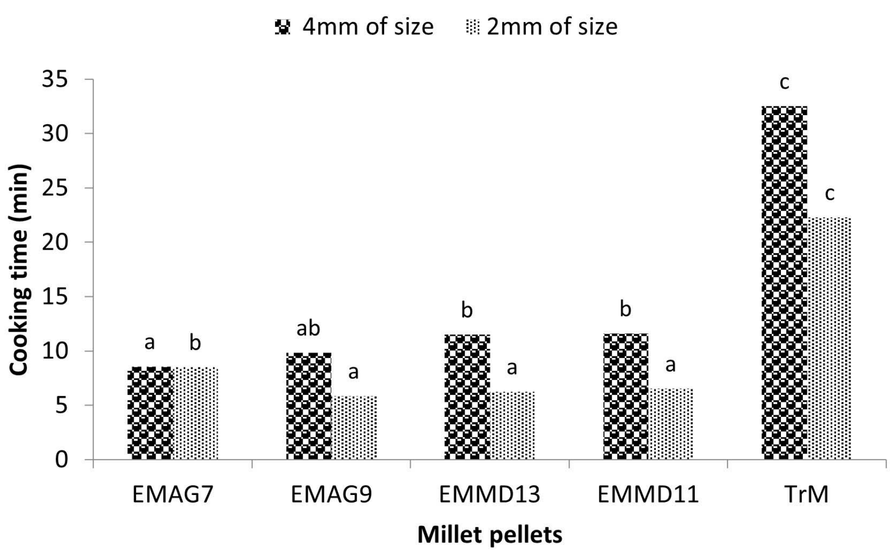

Figure 3. The average cooking time for millet granules. For the same cooking time, granules that are followed by the same letter do not show any significant differences at the 5% significance level.

4. Discussion

The development of pre-cooked millet flour rolled millet flour represents a newly introduced process in food production. These fast cooking granules were made out of extruded millet flour (firstly moistened to 26% moisture content) and hydrocolloids. In fact, after the extrusion of millet grits at temperatures between 110 to 120˚C, dried and ground. To aid in the granule formation, either Arabic gum or maltodextrin was added to the mixture. Rolled millet flour yields were measured using two sieves of 2 mm and 4 mm mesh size mesh sizes to assess the size of the produced granules. Between the two additives, Arabic gum proved to be more effective in assisting the rolling process of the extruded millet flour that has been moistened with 26% water. This enhanced efficiency in the agglomeration (or binding together) of the millet flour granules was evident from the fact that Arabic gum requires a lower incorporation rate to achieve the desired rolled millet flour yield. In other words, the yields of 2 mm granules were higher when Arabic gum was used compared to those obtained with maltodextrin. According to [7], the effectiveness of hydrocolloids like Arabic gum in this process could be attributed to the chemical structure and conformation of the polymer in solution, which influences the hydrocolloid's ability to function in the food system. These functions include developing the structure of the granule formation, modifying the textural properties of the food system, and the starch functionality of the final product.

The water absorption index (WAI) measures how much water is absorbed by starch, which is an important indicator of starch gelatinization and its integrity when dispersed in water. A higher WAI typically reflects better starch gelatinization. The water solubility index (WSI), on the other hand, is a measure of the degree of starch degradation, as it indicates how much starch dissolves in water. The WSI is influenced by the interactions between molecules within the starch structure—specifically, the extent of intra- and intermolecular interactions in both the amorphous (disordered) and crystalline (ordered) regions of the starch granules. These interactions are key to the stability and behavior of starch during processing [12].

Extrusion cooking, a method used in the preparation of pre-cooked millet granules, increases both the WAI and WSI. The process of extrusion affects the starch in different ways depending on the conditions. In our case, when extruded millet flour (EM) is produced, both its water absorption and solubility increase. Specifically, the introduction of Arabic gum (AG) and maltodextrin (MD) during extrusion influences the water absorption and solubility of the millet granules.

When starch undergoes gelatinization during extrusion, the crystalline structure of the starch is disrupted. This disruption occurs because the inter- and intramolecular hydrogen bonds that hold the starch molecules together are broken. As a result, more hydroxyl groups (the water-attracting parts of the starch molecules) are exposed, which increases the starch's ability to absorb water. Additionally, water molecules can more easily diffuse into the amorphous (less ordered) part of the starch granules, further increasing water absorption. As a result of these changes, the water absorption index of extruded starch is typically higher than that of native, unprocessed starch, as confirmed in previous studies like [13].

This is consistent with findings from [14], where extrusion was shown to reduce the crystallinity of sorghum starch. This reduction in crystallinity was linked to an increase in the water absorption index of the starch, highlighting how extrusion can alter the structural properties of starch.

However, the water solubility index (WSI) behaves differently when starch undergoes dextrinization or melting, rather than just gelatinization. When dextrinization (a process where starch molecules are broken down into smaller sugars) or starch melting predominates, the WSI typically decreases. This indicates that the starch is degrading and becoming more soluble in water, which can occur if the extrusion process breaks down the starch too much, as mentioned by [15].

Additionally, both the WAI and WSI of extruded millet flour granules depend on the specific conditions during the extrusion process. As the extrusion temperature increases, the starch's amylose and amylopectin chains (the two main components of starch) separate. This separation allows the starch to form an expandable matrix, which increases the water absorption index (WAI). The shear forces applied during extrusion further help to break down the starch and increase its water solubility (WSI), as reported by [15] [16].

In terms of the additives used, Arabic gum (AG) and maltodextrin (MD), both reduce the water absorption of pre-cooked millet pellets. However, their effect on the water solubility index differs: with a higher concentration of MD, the solubility of the millet pellets increases, while with more AG, the solubility decreases. This difference is largely due to the properties of the additives themselves—maltodextrin is more soluble than Arabic gum, which helps explain the observed differences in solubility between the pellets made with Arabic gum (EMAG) and those made with maltodextrin (EMMD).

The sizing characteristics of millet flour granules are determined using a Rapid Visco Analyzer (RVA Model 4500, Perten Instrument, Australia), which measures various key parameters such as pasting temperature, maximum viscosity, degradation viscosity, final viscosity, and setback viscosity. These parameters give a comprehensive understanding of how the starch behaves under different conditions during processing, especially during cooking and cooling.

Pasting Temperature is a parameter that refers to the minimum temperature at which starch begins to swell and gelatinize, marking the point where the starch particles absorb water and undergo a transformation from a crystalline to a more amorphous structure. This is the first step in starch cooking and is important because it determines how well the starch will perform in the final product. When starch gelatinizes, it thickens and forms a gel-like structure. The pasting temperature helps identify the beginning of this process.

Peak Viscosity represents the highest viscosity (thickness) reached during the cooking process. It shows the maximum swelling of starch granules and indicates the degree of starch gelatinization. The higher the peak viscosity, the more starch has gelatinized and absorbed water. This provides insight into how well the starch will form a smooth, stable paste when it is cooked.

Breakdown Viscosity refers to the reduction in viscosity after reaching peak viscosity, which occurs due to the breakdown of starch under the high heat and shear forces applied during cooking. Breakdown viscosity reflects the stability of the starch dough. A higher breakdown viscosity indicates that the starch paste is more susceptible to degrade, meaning the dough is less stable and more prone to deterioration under processing conditions.

Recoil Viscosity measures the ability of the dough to recover its viscosity after it is cooled. During cooking, starches undergo swelling and gelatinization, but after cooking, they may revert to a more solid or firm state due to retrogradation (the amylose networking while excluding water). Recoil viscosity gives insight into how well the starch can recover after heating and cooling, and it is often associated with the tendency of starch to retrograde. High recoil viscosity suggests that the starch will regain its structure during cooling, while lower values suggest that the starch may be more prone to retrograde and lose its structure over time.

Final Viscosity provides the viscosity of the starch paste after cooking and cooling, giving an indication of the paste's resistance to shear stress during agitation. Final viscosity indicates how well the starch can hold its structure once it has been gelatinized, cooked, and then cooled. A higher final viscosity means that the starch forms a thicker, more stable paste that can better withstand stirring or other mechanical stresses during processing [17].

The results shown in **Table 3** indicate that extrusion cooking affects these bonding parameters of pre-cooked millet flour granules. Specifically, lower setback viscosities were found in both the extruded flour and hydrocolloid formulations, which suggests that these mixtures have a reduced tendency for starch retrogradation after extrusion. Retrogradation is the process where starch molecules, after being gelatinized, reassemble into a more crystalline structure, which leads to a firmer texture. Lower setback viscosity means the starch is less likely to retrograde, which is beneficial for maintaining a smooth texture in the final product. This is particularly important when producing resistant starch, which is less digestible and has health benefits, as noted by [18].

These findings can be linked to peak viscosity, indicating the degree of starch gelatinization. A higher peak viscosity corresponds to a higher degree of gelatinization, which would make the starch more likely to resist retrogradation. The pasting temperature corresponds to the temperature at which the viscosity begins to increase, indicating the start of starch gelatinization. Interestingly, slurries with the same pasting temperature can have similar cooking times, suggesting that this temperature is crucial in determining how long starches take to cook [19]. A higher degradation viscosity indicates that the starch is less resistant to heat and shear forces during cooking. In other words, a starch paste with higher breakdown viscosity is less stable, which means it is more likely to degrade when exposed to high heat or mechanical stress. This degradation can lead to the formation of resistant starch during retrogradation, which has beneficial health properties [20].

The reduced final viscosity values observed in fast cooking millet flour granules may result from less degradation of the starch fraction during extrusion, as well as the disruption of starch's molecular structure. Extrusion can break down the starch's crystalline structure, reducing its ability to form a thick, stable paste. This reduction in final viscosity means the dough is more resistant to shear stress during agitation, making it more stable and easier to handle during processing [12].

Finally, cooking-extrusion influences the cooking time of granules formulated with hydrocolloids. This cooking time is also an indicator of starch gelatinization and the integrity of the starch in aqueous dispersion. During the cooking-extrusion process, starch undergoes several transformations, such as gelatinization, melting, and fragmentation. The extent of these transformations depends on several factors, including the moisture content of the starch, the pressure applied, the temperature during extrusion, and the shear force during processing [21]. The changes in these parameters during extrusion help determine the final texture and properties of the granules. Furthermore, to address the scalability and integration with existing food processing technologies. Critically analyzing limitations, including storage stability, climate effects, and nutrient-hydrocolloid interactions would be important to follow.

5. Conclusions and Future Trends

The application of cooking-extrusion technology was demonstrated in the formulation of fast cooking millet flour granules called instant "Arraw", with the incorporation of hydrocolloids such as Arabic gum or maltodextrin. The total yields of obtained millet flour granules were found to be lower than those achieved with traditional millet flour, which served as a control in the study. However, it is important to note that no significant difference was observed in the yield of 2 mm granules between the fast cooking millet flour granules and the control.

In terms of other properties, the solubility and water absorption of the fast cooking millet flour granules were higher than those of the traditional control. This suggests that the extrusion process, in combination with the addition of hydrocolloids, may have facilitated an increase in the granules' ability to absorb water, which is important for the cooking process and the texture of the final product.

A key advantage of the fast cooking millet flour granules is the significantly reduced time required to prepare porridge from millet "Arraw". This reduction in cooking time can be seen as a major benefit, especially for households, as it leads to time savings and improves convenience. From a market perspective, the reduced cooking time also enhances the competitiveness of the product, as consumers often seek quick and easy meal solutions.

However, one limitation observed was that the viscosity of the porridges made from the fast cooking millet flour granules was lower compared to those made from traditional millet flour. This lower viscosity could affect the texture and mouthfeel of the porridge, which may impact consumer preference.

Looking ahead, further research will be conducted to investigate the nutritional and thermal properties of the fast cooking millet flour granules, as well as their potential for fortification. Furthermore, plant materials such as carrot, mango and others could be added to the formulated fast cooking granules for increasing the dry matter content and micronutrient level. By optimizing these properties, it is expected that the functionality and appeal of the product can be improved to meet consumer needs and enhance its nutritional value. In fact, a sensory evaluation to assess the palatability and acceptability of the modified "Arraw", as well as an analysis of changes in micronutrient content and bioavailability, were already mentioned in another paper that is set to be published.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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