Research, Society and Development, v. 13, n. 5, e5613545432, 2024
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v13i5.45432

Evaluation of the rheological properties of stirred yogurt thickened with modified cassava (*Manihot esculenta*, Crantz) and taro (*Colocasia sp.*) starch

Avaliação das propriedades reológicas de iogurte batido espessado com amido modificado de mandioca (*Manihot esculenta, Crantz*) e taro (*Colocasia sp*.)

Evaluación de las propiedades reológicas de yogurt batido espesado con almidón modificado de yuca (*Manihot esculenta, Crantz*) y taro (*Colocasia sp.*)

Received: 03/21/2024 | Revised: 04/28/2024 | Accepted: 05/13/2024 | Published: 05/16/2024

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Abstract
This study aimed to assess the impact of modified cassava (Manihot esculenta Crantz) and taro (Colocasia sp.) starches on the rheological properties of homemade yogurt. Five treatments were tested: yogurt thickened with 0.5% (AM 0.5%) and 1% (AM 1%) cassava starch, yogurt thickened with 0.5% (AI 0.5%) and 1% (AI 1%) taro starch, and a control (yogurt without any thickener). The starches were subjected to physical modification and were incorporated into the yogurt, and then evaluated for rheological properties, apparent viscosity, texture, water retention capacity and syneresis. The result showed that the apparent viscosity was higher in yogurts produced with starches at all analysis speeds, however, the control treatment only showed significant differences with AM 0.5% and AI 0.5% ($p<0.05$). In the evaluation of firmness, syneresis, consistency coefficient (k), and flow index (n), yogurts made with starch exhibited the highest values, showing significant differences ($p<0.05$) compared to the control treatment. The water retention capacity (WHC) values indicated significant differences between the control yogurt and the yogurt produced with thickeners, except AI 1% ($p<0.05$). For adhesiveness, no significant differences ($p>0.05$) were observed between starch and control treatments. The study concluded that modified cassava and taro starch improves the rheological properties of homemade yogurt, specifically in apparent viscosity, consistency, and firmness, and reduces the occurrence of syneresis.
Keywords: Homemade yogurt; Starch; Taro; Cassava; Rheological properties.

Resumo
A presente pesquisa foi realizada com o objetivo de avaliar o efeito do amido modificado de mandioca (*Manihot esculenta Crantz*) e de taro (*Colocasia sp*.) na melhoria das propriedades reológicas de iogurte caseiro. Foram utilizados cinco tratamentos especificamente iogurte espessado com 0.5% (AM 0.5%) e 1% (AM 1%) de amido de mandioca, iogurte espessado com 0.5% (AI 0.5%) e 1% (AI 1%) de amido de taro e controle (iogurte sem espessante). Os amidos foram modificados fisicamente, aplicados no iogurte e se analisaram às propriedades reológicas, viscosidade aparente, textura, capacidade de retenção de água e sinérese. O resultado mostrou que a viscosidade aparente foi maior nos iogurtes produzidos com amidos em todas as velocidades de análise, no entanto, o tratamento controle, apenas apresentou diferenças significativas com AM 0.5% e AI 0.5% ($p<0.05$). Na avaliação da firmeza, sinérese, coeficiente de consistência (k) e índice de fluidez (n) os maiores valores foram registrados nos iogurtes produzidos com amido, com diferenças significativas ($p<0.05$) em relação ao tratamento controle. Os valores da capacidade de retenção de água (CRA) indicaram diferenças significativas entre o iogurte controle e o iogurte produzido com espessantes, exceto IA 1% ($p<0.05$). Para adesividade não foram observadas diferenças significativas ($p>0.05$) entre os tratamentos com amido

e controle. O estudo concluiu que o amido modificado de mandioca e taro melhora as propriedades reológicas do iogurte caseiro, especificamente na viscosidade aparente, consistência e firmeza, e reduzem a ocorrência de sinérese.
Palavras-chave: Iogurte caseiro; Amido; Taro; Mandioca; Propriedades reológicas.

Resumen

La presente investigación se realizó con el objetivo de evaluar el efecto del almidón modificado de yuca (*Manihot esculenta Crantz*) y taro (*Colocasia sp.*) en la mejora de las propiedades reológicas del yogur casero. Se utilizaron cinco tratamientos específicamente yogur espesado con 0.5% (AM 0.5%) y 1% (AM 1%) de almidón de yuca, yogur espesado con 0.5% (AI 0.5%) y 1% (AI 0.5%) de almidón de taro y control (yogur sin espesante). Los almidones se modificaron físicamente, se aplicaron al yogur y se analizaron sus propiedades reológicas, viscosidad aparente, textura, capacidad de retención de agua y sinéresis. El resultado mostró que la viscosidad aparente fue mayor en los yogures elaborados con almidones en todas las velocidades de análisis, sin embargo, el tratamiento control solo mostró diferencias significativas con AM 0.5% y AI 0.5% ($p<0.05$). Al evaluar firmeza, sinéresis, coeficiente de consistencia (k) e índice de fluidez (n), los valores más altos se registraron en los yogures elaborados con almidón, con diferencias significativas ($p<0.05$) con relación al tratamiento control. Los valores de capacidad de retención de agua (WHC) indicaron diferencias significativas entre el yogur control y el yogur elaborado con espesantes, excepto AI 1% ($p<0.05$). Para la adhesividad, no se observaron diferencias significativas ($p>0.05$) entre los tratamientos de almidón y control. El estudio concluyó que el almidón modificado de yuca y taro mejora las propiedades reológicas del yogur casero, específicamente en la viscosidad, consistencia y firmeza aparente, y reduce la aparición de sinéresis.
Palabras clave: Yogur casero; Almidón; Taro; Yuca; Propiedades reológicas.

1. Introduction

Yogurt is a milk-based product having high nutritional value with a different amount of protein, fat, minerals, and vitamins (Mahmoudi et al., 2014; Tamime & Robinson, 2007). Is a popular food in the world having significant nutritional benefits as well as a high probiotic count and superior physicochemical and textural properties with desirable sensory attributes (Mousavi et al., 2019). Yogurt shows very interesting gastrointestinal health benefits such as lactose intolerance due to its good digestibility compared to milk, constipation, diarrheal diseases, colon cancer, inflammatory bowel disease, and *Helicobacter pylori* infection (Bernat et al., 2015).

Texture, gel consistency, and flow properties are the main components of the quality of the yogurts (Arab et al., 2022). In yogurt production, problems associated with physical and rheological characteristics specifically, textural defects such as weak gel firmness and the presence of syneresis, have been reported as rejection factors by consumers (Agyemang et al., 2020; Arab et al., 2022). In this context, various technological alternatives have emerged, such as the utilization of starches, transglutaminase enzyme, guar gum, xanthan gum, and protein-based components, which include skimmed milk powder (SMP), whey protein-based powders (WP), and casein-based powders (CP). Additionally, modifying processing conditions like homogenization, fermentation, and cooling alongside other hydrocolloids, can enhance texture, consistency, and viscosity. These methods also reduce syneresis, thereby improving the physical stability and acceptability of the product (Arab et al., 2022; Batista et al., 2022; Bravo-Núñez et al., 2019).

The use of modified starch as a texturiser has already been tested in both stirred and set-type yogurts with levels ranging between 0.01% and 2%, but without elucidated results (Bravo-Núñez et al., 2019). A study by Agyemang et al. (2020) indicates that using starches from cassava varieties (Abrabopa, AGRA, and Bankye hemaa) as an additive in yogurt reduces syneresis during its preparation. Moreover, a sufficient concentration of starch (0.75% and 1%) extracted from yellow-skinned potatoes resulted in improved syneresis, consistency, and sensory evaluation, according to Altemimi (2018). Conversely, Pérez et al. (2021) assessed the use of starch from two yam varieties (Dioscorea spp.) and found that both varieties exhibit a higher capacity to absorb and retain water, leading to gels with higher viscosity, reduced syneresis, and the maintenance of an intense white color. Shaheryar et al. (2023) successfully used 2% starch from taro to reduce the occurrence of syneresis and upgrade the water-holding capacity, viscosity, texture, and appearance in yogurt, increasing storage days.

In Xai-Xai city, homemade yogurt is a significant part of trade for many families who rely on livestock for their livelihood. This yogurt is made without additives and requires storage if not sold on the production day. These conditions contribute to syneresis occurrence, resulting in yogurt with an inconsistent body and reduced gel consistency, viscosity, and texture, diminishing the product's quality. To overcome these problems, the current study was conducted to assess the potential of modified cassava (Manihot esculenta Crantz) and taro (Colocasia sp.) starches as thickeners in stirred cow's milk yogurt marketed at the bridge over the Limpopo River in Xai-Xai city - Mozambique, due to their ability to enhance texture and reduce syneresis.

2. Methodology

The research was conducted at the laboratory of food of the Faculty of Engineering (FENG) at Eduardo Mondlane University and in the Chemistry laboratory at Save University (UniSave), Mozambique.

Sample

The sample consisted of stirred yogurt, made using the traditional method employed by vendors on the bridge over the Limpopo River in Xai-Xai city, with modifications in the thickening process according to the flowchart in Figure 1. The yogurt was produced from fresh cow's milk, with the addition of modified starch from cassava (Manihot esculenta Crantz) and taro (Colocasia sp.) known locally as *Madumbi*.

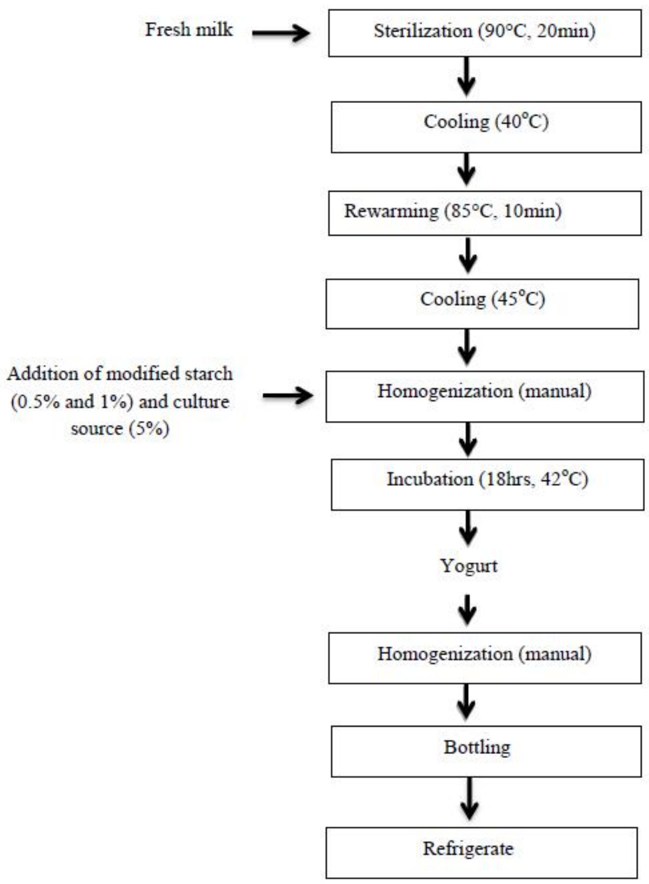
The milk was purchased from the Nguluzane Agro-pecuária company in Xai-Xai city, in the early hours of the day and was transported in a thermal box with excess ice to UniSave chemistry laboratory. Fresh taro and fresh cassava were purchased from the Xai-Xai wholesale market on the day of use. The study consisted of 5 treatments represented in Table 1.

Table 1 - Treatments used in the experiment and percentage of starch addition.

Treatment	Yogurt with Modified Starch Proportion (%)	Treatment Designation
1	Yogurt with cassava starch (0.5%)	AM 0.5%
2	Yogurt with cassava starch (1%)	AM 1%
3	Yogurt with taro starch (0.5%)	AI 0.5%
4	Yogurt with taro starch (1%)	AI 1%
5	Yogurt without starch (0%)	Control

Source: Authors.

Figure 1 - Yogurt production flowchart and packaging.



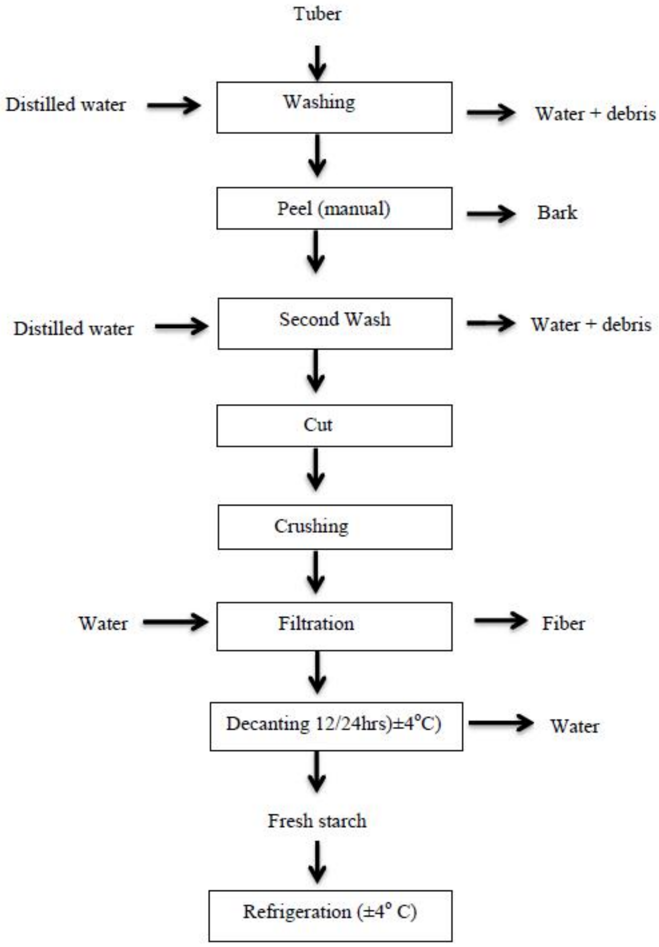
Source: Authors.

Starch extraction

The starch was extracted using the classic method of decanting, with some adaptations regarding the grinding (kitchen blender) and the medium (distilled water) in which the filtration was carried out.

Cassava decantation took place for 12 hours and taro for 24 hours due to the mucilage, both under refrigeration at 4 ºC. Filtration was performed on a strainer of approximately 100 mesh (Kringel et al., 2020). The extraction process described above is represented in the flowchart of Figure 2.

Figure 2 - Flowchart of starch extraction in tubers.



Source: Authors.

Modification of starch

For this research, the starches were subjected to physical modification, by humidification (Punia, 2020; Zia-ud-Din et al., 2017). The starch was heated to a higher temperature than the initial gelatinization temperature (60ºC) with insufficient humidity to cause gelatinization in a short period and the product obtained was a pre-gel.

Viscosity

The apparent viscosity was determined at room temperature (24±1°C), by direct reading in a Bohlin Visco 88 rotational viscometer, connected to a thermostatic bath. For the analysis of all treatments, position two and speeds ranging from 35rpm to 1000rpm were used (Hussain et al., 2022; Najgebauer-Lejko et al., 2020).

Texture

For texture analysis, the penetration test, on the texture analyzer Instron series 5542, was used, and the reading was performed at a storage temperature of 10ºC, with the aid of the Instron software 24. Test conditions were limited to 1.0 mm/s speed for the pre-test, test speed was 1.0 mm/s and post-test was 1.0 mm/s; penetration distance was 70%, contact time 5s;

contact force 400g. The device used was a 25 mm diameter aluminum cylinder probe, and the sample volume was 10 ml (Pang et al., 2019).

Water holding capacity

The water holding capacity (WHC) was determined using the centrifugation method, where 5g of yogurt was placed in a calibrated tube and centrifuged at 4500rpm (15000xG) for 15 min at 20°C in a HERMLE Z 200 A centrifuge. The water-holding capacity was calculated using Equation 1 (Pang et al., 2019).

$$\textbf{WHC} = [1 - (\text{weight of serum after centrifugation/weight of yogurt sample}) \times 100] \qquad (1)$$

Syneresis

Syneresis was determined using the drainage method (Hussain et al., 2022). 100g of yogurt was distributed on filter paper over a funnel at 4ºC and after four hours of drainage, the volume of the whey was collected and quantified. The syneresis index was expressed in percentage (w/w) using Equation 2:

$$\text{Syneresis } (\%) = [(\text{whey weight/yogurt sample weight}) \times 100] \qquad (2)$$

Statistical analysis

Statistical analysis was performed in the statistical software SPSS student version 22.0. The results were submitted to analysis of variance - ANOVA (one way), to verify the assumptions, normality, and homogeneity of variance, as well as the multiple comparisons of the means in the Tukey test. Differences between treatments were considered significant when $p<0.05$.

3. Results and Discussion

Apparent viscosity

Table 2 shows the average apparent viscosity in centipoise of the yogurt at different strain rates ($\dot{Y}$1/s), represented by the speeds applied to the viscometer, which varied from two corresponding to 35rpm to eight corresponding to 1000rpm.

Table 2 - Apparent viscosity of yogurts as a function of strain rates.

		Treatments				
Parameter	**Positional speed**	**AM 0.5%**	**AM 1%**	**AI 0.5%**	**AI 1%**	**Control**
Apparent viscosity (cP)	2	619±0.01^{b}	511±0.01^{a}	532±0.01^{ab}	475±0.01^{a}	449±0.05^{a}
	3	346±0.01^{a}	339±0.01^{a}	329±0.03^{a}	321±0.00^{a}	125±0.01^{b}
	4	240±0.00^{b}	199±0.00^{a}	207±0.00^{a}	195±0.00^{a}	179±0.01^{a}
	8	25±0.00^{b}	20±0.00^{a}	21±0.00^{ab}	20±0.00^{a}	19±0.00^{a}

Equal letters on the same line indicate no significant differences in Tukey's test at 5% significance. Source: Authors.

The apparent viscosity was higher in the yogurt produced with starches, at all analysis speeds, as expected (Prajapati et al., 2016). Similar results were recorded in other studies (Ahmed & Hamed, 2015; Imbachí-Narváez et al., 2019; Pérez et al., 2021; Wong et al., 2020). In another study, the modified starch improved the properties of yogurt more effectively than natural starch at 0.5% concentration, in terms of yield stress, consistency, apparent viscosity, thixotropy, and pseudoplasticity (Pang et al., 2019). Similar results were observed in a study with native starch of taro (*Colocassia esculenta*) (Shaheryar et al., 2023).

The highest values of apparent viscosity recorded at lower speeds (two and three) and the lowest value of viscosity, at maximum speed (eight), indicate the inverse relationship between apparent viscosity and velocity gradient, which confirms the pseudoplasticity of the analyzed yogurt (Khodadadi et al., 2023; Pang et al., 2019). The decrease in viscosity as a function of the increase in the strain rate, also confirms that the yogurt obtained in this study presents a behavior of non-newtonian fluids and obeys the rheological models of Herschel-Bulkey and Power Law with $n<1$ (Najgebauer-Lejko et al., 2020; Nielsen, 2017; Prajapati et al., 2016). As it is a real fluid, one of the reasons why it has a higher apparent viscosity at low speeds is the fact that the force of agitation at these speeds is insufficient to break the cohesive forces between the gel molecules in yogurt (Mary et al., 2022; Nielsen, 2017). The decrease in apparent viscosity at higher speeds is due to the weakening of the interactions existing between the product molecules and the decrease in the interaction energy between them with the increase in the strain rate (Khodadadi et al., 2023; Mary et al., 2022). One of the reasons why it has a higher apparent viscosity at low speeds is that the force of stirring at these speeds is insufficient to break the cohesive forces between the gel molecules in yogurt (Khodadadi et al., 2023; Mary et al., 2022; Pang et al., 2019).

Regarding speeds two (35rpm), four (107rpm), and eight (1000rpm), the AM 0.5% treatment exhibited significant differences ($p<0.05$) compared to other treatments, except for AI 0.5%. The control treatment, while displaying the lowest apparent viscosity, only showed significant differences when compared to AM 0.5% and AI 0.5% ($p<0.05$). At speed three (61rpm), the control treatment differed significantly ($p<0.05$) from the starch-thickened treatments according to the Tukey test. Consequently, yogurt treated with modified starch demonstrates higher apparent viscosity at all tested speeds.

Rheological parameters

Table 3 shows the values of flow index (n) and consistency coefficient (k) of the Power Law model $n<1$, which fits better with dairy products (Prajapati et al., 2016).

The flow rates of the yogurt made with thickeners were similar, having shown differences with the control treatment in the order of 0.3. The values of (n) recorded in all treatments confirm that the elaborated yogurt presents a pseudoplastic behavior since they are below one and above zero ($n<1$) (Khodadadi et al., 2023; Nielsen, 2017; Pang et al., 2019; Prajapati et al., 2016). The lower the value of the flow index (n) the greater the shear thinning and the product will tend to reduce its viscosity values with increasing strain rate (Hussain et al., 2022; Nielsen, 2017). Taking this statement into account, it can be seen in Table 2 that the control treatment showed greater pseudoplastic behavior compared to the thickened yogurt. The lowest value of consistency coefficient (k) in the control treatment also responds to what was expected since this treatment had the lowest apparent viscosity and greater syneresis (Hussain et al., 2022; Prajapati et al., 2016). Similar behavior was observed in stirred-type yogurt with yam starch (Pérez et al., 2021), and in yogurt prepared with starches of three new Ghanaian cassava varieties as a thickener (Agyemang et al., 2020).

Table 3 - Rheological parameters of the Power Law model $n<1$.

	Treatments				
Parameters	**AM 0.5%**	**AM 1%**	**AI 0.5%**	**AI 1%**	**Control**
n	0.23	0.23	0.23	0.23	0.20
k ($Pa.s^n$)	1.08	0.96	0.98	0.91	0.55
R^2	0.99	0.99	0.99	0.98	0.92

Source: Authors.

To verify the adjustment of the Power Law model (n<1) for the experimental data, the magnitude of the coefficient of determination (R^2) was considered, where the values for all treatments varied from about 0.92 to 0.99, confirming the adjustment of the model. When the values of (R^2) are closer to the unit (one), the model is more appropriate in the relationship of variables (Dircio-Morales et al., 2023; Nielsen, 2017; Prajapati et al., 2016). Pérez et al. (2021) reported that models carried out from shearing-process data, seem to be the best ways of describing the flow behavior of stirred yogurts, because of the highly time-dependent behavior of the product, which agrees with the result of the current study.

Texture

Table 4 presents the firmness and adhesiveness of the yogurt, which are the two parameters analyzed and deemed most crucial in assessing the texture profile. Firmness refers to the force required to deform the product by the consumer, while adhesiveness measures the degree to which the food sticks or adheres to the oral mucosa surface during consumption (Prajapati et al., 2016).

Table 4 - Texture profile in yogurt.

	Treatments				
Parameter	**AM0.5%**	**AM1%**	**AI0.5%**	**AI1%**	**control**
Firmness (kPa)	0.20 ± 0.1^{c}	0.14 ± 0.1^{b}	0.10 ± 00^{a}	0.10 ± 00^{a}	0.09 ± 00^{a}
Adhesiveness	-22.87 ± 0.7^{a}	-22.74 ± 0.2^{a}	-22.87 ± 0.9^{a}	-22.93 ± 0.1^{a}	-22.84 ± 00^{a}

Equal letters on the same line indicate no significant differences in Tukey's test at 5% significance. Source: Authors.

The values in Table 4 indicate that firmness was higher in treatments with starch. In the statistical evaluation, the treatment AM 0.5% showed a significant difference with the other treatments in the Tukey test ($p<0.05$), the same was verified with the treatment AM 1% ($p<0.05$). The firmness result indicates that the AM 0.5% treatment had a more cohesive and firmer gel structure, difficult to break compared to the structure of the other yogurt, resulting from the action of the thickener (Prajapati et al., 2016). The AM 1% treatment showed higher adhesion value, however, in the Tukey test, the yogurt did not show significant differences ($p>0.05$). About firmness, the lowest value recorded in the control treatment and the highest in the AM 0.5% treatment, confirm that less viscous products tend to have a lower firmness and those with greater viscosity greater firmness (Mudgil et al., 2017). The greater value of adhesiveness recorded in the AM 1% treatment is due to the negativity of the recorded values, the more negative it is the stickier the food. The adhesiveness increases with the negativity of the recorded values (Prajapati et al., 2016). The use of starch was reported to result significant increase in thickness, mouth-feel, and creaminess in yogurt (Agyemang et al., 2020). Pang et al. (2019) reported similar results in their study of the physiochemical properties of yogurt produced with commercial modified starch, as well as Hussain et al. (2022) in non-fat yogurt containing cress seed gum and various starches.

Water holding capacity

The yogurts treated with starch showed higher water holding capacity (WHC) than yogurt prepared without thickeners (control). The values described in Table 5, indicate that the control sample showed significant differences in the Tukey test with the yogurt treated with thickeners, except AI 1% ($p<0.05$). The reason why yogurt enhanced with starch exhibits a higher water retention capacity is due the gel-like structures formation, which inhibit water loss from the matrix. Consequently, this confers water retention, fosters an excellent emulsion, and increases viscosity (Pang et al., 2019; Tamime & Robinson, 2007). Shaheryar et al. (2023) found that incorporating 2% taro starch bolsters the water-holding capacity, corroborating with the findings of this study.

Table 5 - Values of water holding capacity in yogurt treatments.

Treatment	Water holding capacity %
AM 0.5%	62.64±1.43[a]
AM 1%	66.52±1.00[b]
AI 0.5%	70.40±0.43[c]
AI 1%	59.42±0.70[d]
control	58.51±0.39[d]

Equal letters in the same column indicate no significant differences in Tukey's test at 5% significance. Source: Authors.

Syneresis

According to the data in Table 6, significant differences were observed ($p<0.05$) between the control and starch-treated yogurt, indicating the influence of starches in syneresis reduction. However, the AM 0.5% treatment, which had the lowest syneresis index, showed significant differences ($p<0.05$) compared to the rest of the treatments. The lower index of syneresis registered in the AM 0.5% treatment is justified by the higher apparent viscosity observed (Table 2), since the higher the viscosity, the greater the interconnection network of macromolecules that balances the matrix of the yogurt, and when this occurs, less syneresis is expected (Prajapati et al., 2016).

Two reasons can explain this behavior, the first is the fact that the modified starch is a polysaccharide with thickening properties, which during the fermentation process, interacts with the casein molecules, fortifying the gel structure and preventing the whey from leaving (Arab et al., 2022). On the other hand, when the isoelectric point (pH 4.6) is reached, the starch interacts with the aqueous phase of the system where the whey increases the firmness of the gel and prevents the whey from leaving (Arab et al., 2022; Hussain et al., 2022; Prajapati et al., 2016). Agyemang et al. (2020) showed the efficiency of cassava starch on syneresis reduction. Yogurt with yam starch at 0.1% w/w, showed a decrease in syneresis, and the same was observed in yogurt with 0.75 and 1% of sweet potato starch (Altemimi, 2018; Pérez et al., 2021; Saleh et al., 2020).

Table 6 - Values of syneresis in yogurt treatments.

		Treatment				
Parameter	**Day**	**AM 0.5%**	**AM 1%**	**AI 0.5%**	**AI 1%**	**control**
Syneresis (%)	0	4.92±0.30[a]	11.84±0.63[b]	12.86±0.11[b]	13.46±0.11[b]	50.81±2.02[c]

Equal letters on the same line indicate no significant differences in Tukey's test at 5% significance. Source: Authors.

4. Conclusion

Modified cassava and taro starch improve the rheological properties and the body of homemade yogurt sold on the bridge over the Limpopo River in Xai-Xai. Adding 0.5% as well as 1% of modified starch shows no difference. Modified cassava and taro starch reduce the occurrence of syneresis in yogurt. Therefore, further studies should be conducted to compare the rheological properties in yogurts produced with physically, enzymatically, and genetically modified starch from cassava, taro, and other matrixes.

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