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Quinoa and Amaranth Flours and Solvent-Free Extracted Starches: Proximate Composition, Technological and Functional Properties

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Abstract Amaranth and quinoa are low-input, climate-smart crops that are highly nutritious and increasingly in demand. Their flours are utilized in various baking products and other applications, such as sauces. However, solvent-free extracted starches from these crops have not been compared to their flours in diverse products, including meat products. This study examined parameters contributing to functionality in products for water-extracted starch from amaranth and quinoa, comparing it to their flours. Analyses included proximate components, technological properties, and functional properties of the flours and starches. Results indicated significant differences in the proximate content of quinoa, amaranth flours, starches, and corn starch ($p<0.05$). The protein content of hydro-extracted starches was higher compared to alkali-extracted starches from other studies. Corn starch, used as a control, showed no significant difference ($p>0.05$) in the porosity of all flours and starches. Porosity is crucial for fried meat products as it enhances oil uptake. In this study, it was desirably lower than 50% in all starches and flours. The water absorption index was within the recommended range for optimal functionality of flours and starches (2-3.5g/g). Swelling power was higher in extracted starches compared to their flours, which is advantageous for cooked products. The study indicates that quinoa and amaranth starch can serve as substitutes for corn starch in food products, as they exhibit similar properties to the more expensive corn starch. They exhibited better wettability and dispersibility properties. These parameters contribute to products like sausages, enhancing juiciness and texture, which are desirable traits for consumers. Additionally, the emulsion capacity of starches did not significantly differ between flours and starches. Therefore, quinoa and amaranth flours and starches can be used in emulsion products as fat replacements. The properties of water-extracted starches analyzed in this study demonstrate their potential for use in other industries, such as pharmaceuticals, textiles, and packaging materials.

Keywords Product Development, Pseudo Cereals, Extracted Starches, Functional Properties

1. Introduction

Amaranth (Amaranthus hypochondriacus) and quinoa (Chenopodium quinoa Willd) are climate-resilient pseudo cereals native to the Andes. Amaranth and quinoa outperform maize in harsh sub-Saharan environments exacerbated by climate change. While maize suffers from heat stress above 32 ℃ [1], quinoa thrives between -4 ℃ and 38 ℃ [2]. Amaranth and quinoa yield 1.5 -2 and 4.3 tons per hectare, respectively, in hot, dry conditions [3,4].

These pseudo cereals are cultivated in South America, Africa, and Asia [5]. Amaranth has also been produced for exportation in Africa [6]. Quinoa world production was about 173,000 metric tons in 2022 [6].

Amaranth grain composition is 12.5-17.6% protein, 1.9-9.7% fat, 2.5-3.2% ash, 3.1-5.0% fiber, and 48-69% carbohydrates. Quinoa grain composition is 10-18% protein, 4.5-8.8% fat, 2.1-4.9% fiber, and 54.1-74.7% carbohydrates [7]. Amaranth's starch accounts for about 60% of the grain [8], while quinoa's starch content is 70% [9]. Amaranth starch contains 1.2%, compared to 8.4% amylose in quinoa starch [10]. Amaranth has been reported to have 85-90% amylopectin, while quinoa has 70-80% [9,11].

Poor nutrition in developing nations in Africa has led to the production of commercial corn starch (starch that has been enhanced with either native proteins or proteins from other sources) [12]. This modification aims to improve the physicochemical properties of the starch, resulting in a product that typically contains between 3% and 10% protein, which is used in high-protein products like soups [12].

Amaranth and quinoa are used in the food industry. They are gluten-free and have reduced starch digestibility, which contributes to a low glycemic index and improved health outcomes [13]. Amaranth and quinoa grains are cooked like rice, while their flours are used in soups, salads, and sauces or in products like breakfast cereals, spaghetti, biscuits, and bread [14]. Additionally, wheat-amaranth blends improve organoleptic characteristics in baked goods [14,15]. Grain amaranth and quinoa starches are also used as thickening agents in various food products [16,17]. Despite the uses of amaranth and quinoa in the food industry, no systematic studies have compared the performance of these flours and their starches, which bring different characteristics to their products.

The use of isolated starch requires its extraction from amaranth and quinoa grains. Noteworthy is that starch is typically extracted using chemical methods, such as soaking grains in sodium hydroxide [16]. This chemical extraction of starch can negatively impact the environment and may lead to the formation of undesirable compounds, thus compromising food-grade standards [18]. Additionally, the use of chemicals increases the production costs of starch. Despite the shortfalls of chemical extraction methods, there is a dearth of information on the properties of quinoa starch that has been obtained using green extraction techniques. Water-based green extraction has been employed in a limited number of studies for quinoa starch [19], but it has not yet been applied to amaranth. Therefore, this study investigated the proximate composition, technological, and functional properties of quinoa and amaranth grains' hydro-extracted starches that were simultaneously compared to those of the same pseudo cereals' flours, highlighting their potential in food product development.

2. Materials and Methods

2.1. Raw Materials

Corn starch A was bought from WFM Starch Products Company, South Africa. The amaranth flour and quinoa grains were bought from Four Season Foods Company, Zimbabwe.

2.2. Flour Preparation

Prior to analysis, the quinoa grains were mechanically processed. Quinoa grains were first dehulled using mortar and pestle and then soaked in warm water overnight to remove saponins. After soaking, the quinoa grains were washed thoroughly and then sun-dried. The sun-dried grains were ground into flour using a laboratory blender (Hamilton Beach-HBF500S-CE). The milled quinoa and amaranth flour, which was bought as flour were sieved using a 500 µm sieve (Universal sieve). For control purposes, the corn starch was also sieved using a 500 µm sieve.

2.3. Starch Extraction

Quinoa and amaranth starch were extracted using a method by Jan et al. [19] with slight modification. Briefly, the flours were steeped in water using a ratio of 1:6 at 4 ℃ for 24 h in a shaking incubator (Bio base -BJPX-100B). Wet milling was done to the mixture for 2 mins using a laboratory blender, and it was passed through 250 µm, 75 µm, and 45 µm sieve. The filtrate was then centrifuged (Bio base -BKC-TH16) at 5500rpm for 15 mins, the supernatant was discarded, and a yellowish layer above the starch cake was removed. The starch cake was suspended in water four times, the centrifugation process was repeated, and the yellowish layer was removed until the cake starch was clear. The starch was dried at 40 ℃ for 12 h in an oven (Scientific South Africa-225) and was kept in sealed plastics until analysis at room temperature. The starch yield of amaranth and quinoa starch was calculated as the amount of starch that was extracted compared to the whole sample mass.

2.4. Proximate Composition Analysis

Moisture, fat, ash, and crude protein for the flours and starches were determined following the AOAC 2005 methods, AOAC-925.10, AOAC-2003.05, AOAC-923.03, and protein AOAC-960.52 respectively. Carbohydrates were calculated by difference.

2.5. Functional Properties and Technological Properties

Bulk density (BD) was analyzed using the procedure outlined by Hyacinthe et al. [20], where 50 grams of the amaranth flour, amaranth starch, quinoa starch, quinoa flour, and corn starch (samples) were placed in a 100 mL graduated cylinder. The volume (Vt) was recorded after leveling the sample with a spatula without tapping the cylinder. BD was then calculated as the mass divided by the recorded volume. Porosity was determined using the BD, and true density was obtained from the analysis.

The wettability of the flour was assessed according to Hyacinthe et al. [20] by measuring the time (in seconds) required for the flour to become completely wet. Starches and flours weighing 1 gram were added to a 25ml measuring cylinder each. The measuring cylinder with the test sample was inverted with a finger placed over the open end and held at a 10cm height from the surface of 500ml distilled water, which was in a 600ml beaker. The finger was removed, and wettability was recorded by measuring the time (in seconds) required for the flour to become completely wet. For dispersibility, the method described by Mora-Escobedo et al. [21] was used with slight modifications. Dispersibility was defined as the difference between the total volume (V0) of the particles immediately after manual stirring and the volume (Vt) of the deposited particles recorded after one hour.

Swelling power and solubility were evaluated using the method by Adebooye and Singh [22]. The amaranth flour, amaranth starch, quinoa starch, quinoa flour, and corn starch (samples) were measured to 500mg each. Distilled water (20ml) was added, and the mixture was heated at 80 ℃ for 30 minutes. It was then cooled to room temperature and centrifuged at 3000 x g for 20 minutes. The supernatant was poured into a weighed petri dish and left to dry at 100 ℃ until there was no change in weight. The weight was recorded. The residues were used to estimate the swelling power, and solubility was calculated based on the supernatant weight. The oil absorption index (OAI) was determined using the method by Adebowale et al. [23], where the OAI was recorded as the weight of the residue after removing the supernatant per unit weight of the original dry sample. The water absorption index (WAI) and water solubility index (WSI) were measured following the method described by Dalbhagat and Mishra [24]. The starch and flour samples were weighed (2 grams) into 50 ml centrifuge tubes, and 20 ml of distilled water was added. Mixing was done for 10 minutes, and it was further centrifuged for 20 minutes at 3000 rpm. The supernatant was then poured into an aluminum dish with known weight and was dried at 105 ℃ for 24 hours in an oven. The weight of the gel and supernatant was recorded. WAI and WSI were calculated.

2.6. Statistical Analysis

One-way Analysis of Variance (ANOVA) was used to analyze proximate analysis and functional properties data using Genstat® 18th Edition (UK). Flours were milled once and sieved. Extractions were also done once for each flour. However, the proximate technological and functional properties analysis was done with three replicates for each sample. Significantly different means at alpha less than 0.05 were separated using Fisher's protracted least significance difference.

3. Results and Discussion

3.1. Starch Yield

The amaranth and quinoa starch yield did not significantly differ ($p > 0.05$) at 44.72±4.88% and 49.30±2.70%, respectively. The amaranth and quinoa starch yields were higher than the 41.2% reported by Kumar et al. [25] for amaranth and the 41–49% range observed by Jan et al. [19] for quinoa starch. The different extraction methods may have affected the starch yield, e.g., the alkali steeping method versus the aqueous steeping used in this study.

3.2. Proximate Composition of Amaranth and Quinoa Flours and Starches

The moisture contents of quinoa and amaranth flour, starches, and corn starch significantly differed ($p < 0.05$) (Table 1). Both quinoa and amaranth flours adhered to the moisture limits set by ISO 712:2011 and AACC International [26], which recommend a maximum of ≤14%. Similarly, starches had moisture levels within the ≤12–14% range specified by ISO 6494:2011.

Amaranth and quinoa starches had significantly lower protein contents than that of corn starch (Table 1). Ramirez-Lopez et al. [27] observed a protein content of 2.46% for quinoa starch, which was lower than the value obtained in this study. This could be attributed to the use of NaOH solution by Ramirez-Lopez et al. [27] in their extraction. Regarding flours, quinoa flour had a significantly higher protein content than that of all other samples. Similarly, amaranth flour had a significantly higher protein content than that of corn starch. The protein contents of quinoa and amaranth flours recorded in this study were within the 10–18% range reported by Jan et al. [7].

Table 1. Proximate composition

	Moisture %	Protein %	Crude fiber %	Fat %	Ash %	Carbohydrates %
Quinoa starch	8.93±0.14[a]	3.33±0.03[b]	0.76±0.04[a]	0.48±0.07[ab]	0.64±0.04[b]	85.86±0.10[e]
Amaranth starch	9.35±0.34[a]	2.78±0.05[a]	2.26±0.08[b]	0.91±0.06[b]	0.74±0.00[c]	83.96±0.42[d]
Corn starch	10.02±0.35[b]	8.87±0.08[c]	0.80±0.17[a]	0.23±0.04[a]	0.26±0.01[a]	79.82±0.49[c]
Quinoa flour	9.81±0.08[b]	14.40±0.15[e]	4.55±0.50[c]	3.84±0.14[c]	2.12±0.01[d]	65.72±0.61[b]
Amaranth flour	10.18±0.17[b]	12.78±0.14[d]	5.03±0.14[d]	5.50±0.63[d]	2.86±0.06[e]	63.66±0.48[a]

Values are means ±standard deviation; values with the same letter in a column are not significantly different ($p > 0.05$). Values are reported on dry basis; $n = 3$

The crude fiber contents of quinoa starch and corn starch did not significantly differ ($p > 0.05$) (Table 1), whereas amaranth flour had the highest crude fiber ($p < 0.05$), followed by quinoa flour and amaranth starch. The crude fiber content of amaranth flour observed in the present study was higher than the 3.83% reported by Thakur et al. [28], whereas that of quinoa flour was lower than the 5.56% reported by the same study. On the other hand, Njoki et al. [29] reported a lower amaranth flour crude fiber value (4.27%) than that obtained in the current study. Amaranth starch in this study was within the 1–5% crude fiber range, and according to Omoregie [30], that range improves texture and consistency in food products. Quinoa starch crude fiber was similar to corn starch, suggesting potential use in products where the reference corn starch has been used.

Amaranth starch fat content was significantly higher than that of corn starch, whereas that of quinoa starch was similar to that in the other starches (Table 1), all of which fell below the ranges reported by Mlakar et al. [31]. According to Mlakar et al. [31], amaranth and quinoa flour fat content ranged from 5.6 to 10% and 4.5 to 8.8%, respectively. On the other hand, the amaranth flour fat content was higher than the 4.08% reported by Sindhu and Khatkar [32]. Omoregie [30] reported that fat in starches enhances the texture and consistency of food products, resulting in a more refined texture. The starches in this study contained fat ranging from 0.23% to 0.91%, which may imply that they have a possibility of improving texture in products. However, when the fat content exceeds 0.1–2%, it can also slow down starch digestion [30], and the starches in this study have fat content that might not slow down starch digestion. Notwithstanding, the starches in the current study were within the recommended range, with amaranth flour registering the highest fat content ($p < 0.05$).

All the samples had significantly different ($p < 0.05$) ash contents (Table 1), with amaranth flour having the highest ash content, followed by quinoa flour, whereas corn starch had the lowest ash content. Thakur et al. [28] observed ash contents similar to those observed in the current study for both quinoa (2.15%) and amaranth (2.35%) flours. Amaranth flour ash content fell within the range reported by Mlakar et al. [31] (2.5–4%), whereas that in quinoa flour was lower than the 2.4–3.7% reported by Bertazzo et al. [33]. Amaranth, quinoa, and corn starch had ash content of less than 1.5%, and according to Omoregie [30], starch ash contents greater than 0.1–1.5% may compromise starch stability during processing, adversely affecting food product quality, as well as starch gelatinization and pasting properties [30]. Therefore, amaranth and quinoa starch, the same as corn starch, may be used in processed foods without affecting their stability.

Starch and flour carbohydrate contents significantly differed ($p < 0.05$) among all samples (Table 1). Corn starch had a significantly lower carbohydrate content than that in amaranth and quinoa starches but significantly higher than that in quinoa and amaranth flours. The carbohydrate content of quinoa flour fell within 54.1–64.2% [33] and 48–69% [7] for amaranth starch. The carbohydrate content in the present study was lower than the 89.76% reported by Contreras-Jiménez et al. [34] for isolated quinoa starch. This difference could be attributed to the varying proximate components of the starches and extraction efficiency.

3.3. Technological Properties

3.3.1. Bulk Density

The BD of starches and flours significantly differed ($p < 0.05$) (Table 2). Corn starch BD was significantly higher than that of amaranth starch but not significantly different from those of quinoa starch and flour. The amaranth and quinoa starches' BD were lower than the 0.63-0.69 g/cm^3 reported by Sindhu and Khatkar [32] and Jan et al. [19]. In the current study, amaranth flour had a BD within the 0.45–0.82 g/cm^3 range reported by Singh and Liu [35]. Sm et al. [36] and Olawuni et al. [37] recorded BD values of 0.714–0.72 g/cm^3 for quinoa flours, higher than those in the present study. The starches herein exhibited slightly lower BD than the recommended range of 0.6–0.8 g/cm^3 for optimal properties.

Table 2. Technological properties

	BD (g/cm^3)	Porosity %	Wettability (seconds)	Dispersibility %
Quinoa starch	0.44 ±0.02^{ab}	46.4 ±6.52^a	20 ±1.34^a	64.33 ±2.08^b
Amaranth starch	0.42 ±0.02^a	47.6 ±16.34^a	43 ±5.45^a	58.33 ±2.52^a
Corn starch	0.46 ±0.00^b	43.4 ±14.39^a	5267 ±169.83^b	59.00 ±1.73^a
Quinoa flour	0.45 ±0.01^b	49.2 ±4.92^a	32 ±4.22^a	60.33 ±2.30^a
Amaranth flour	0.50 ±0.02^c	48.3 ±3.60^a	127 ±5.65^a	71.33 ±0.58^c

Values are means ± standard deviation; values with the same letter in a column are not significantly different ($p > 0.05$). Values are reported on a wet basis; $n = 3$

3.3.2. Porosity

Porosity among the starch and flour samples did not significantly differ (p > 0.05) (Table 2). Sujka and Jamroz [38] reported a corn starch porosity of 52.15%, which is higher than the one obtained in this study. The results of this study suggest that amaranth and quinoa starches and flours can be used in the same products as corn starch, especially where porosity matters most.

3.3.3. Wettability

Corn starch had a significantly higher (p < 0.05) wettability than all other treatments (Table 2). Both amaranth and quinoa starches and flours did not significantly differ. Amaranth and quinoa flour and starch values were lower than the 193.67s wheat flour wettability reported by Hyacinthe et al. [20]. Quinoa and amaranth flour wettability values were greater than 22s of cornflour [39], while quinoa starch had a wettability value similar to that of corn flour. According to Swenson and Katen [40], wettability ensures texture consistency, physical and textural stability in food products, with an optimal range of 10 to 40s. Quinoa starch and flour were in this range, making them potentially preferable for use in products.

3.3.4. Dispersibility

Amaranth starch, corn starch, and quinoa flour did not significantly differ in dispersibility (p > 0.05) (Table 1). However, amaranth flour had significantly higher dispersibility than that of quinoa starch (p < 0.05), which was also higher than that reported by Tanimola et al. [41] (14.92%). Corn starch dispersibility was lower than the 75.50% reported by Awolu et al. [42], and the dispersibility of quinoa flour was approximately double the 34.91% reported by Sm et al. [36]. According to Ashogbon and Akintayo [43], a dispersibility above 50% ensures starches mix well with other ingredients, preventing clump formation and improving consistency, texture, and stability [43]. Samples in this exceeded 50% dispersibility, making them ideal for meat products where clumps are undesirable.

Corn starch is valued in food products for its porosity, and for that property, it is often used in batters and coatings for fried items like chicken. Its porosity helps create a crispy texture by absorbing oil during frying. It is also used in potato chips or puffed snacks for its porosity, which contributes to their light and airy texture. Therefore, quinoa starch, quinoa flour, amaranth starch, and amaranth flour that were analyzed in this study can be used in the same products where corn starch was used because they exhibited porosity values that had no significant difference (p>0.05). For its wettability and dispersibility, corn starch was used in instant soups and sauces. It was used to ensure smooth dispersion in water, preventing clumping and creating a uniform texture for the soups and sauces. In products like beverage powders, puddings, and custards, corn starch is commonly utilized for its beneficial technological properties. However, this research suggests that quinoa starch, quinoa flour, amaranth starch, and amaranth flour could serve as viable alternatives. Notably, these alternatives demonstrated superior wettability, requiring fewer seconds to achieve the desired results compared to corn starch.

3.4. Functional Properties

3.4.1. Swelling Power and Solubility Index

Amaranth starch showed the highest swelling power (Table 3), while the other samples had no significant difference in the swelling power. Amaranth and quinoa flour exhibited lower swelling power than that of the starches, suggesting the presence of amylose–lipid complexes owing to higher fat content in flours than in starches. Siwatch et al. [44] reported a swelling power of 7.55 g/g for amaranth flour, whereas Sindhu and Khatkar [32] found 12.02 g/g. These differences might be due to starch damage due to high temperatures of around 85oC in the methods used for swelling power analysis [45]. Quinoa flour's swelling power of 5.26 g/g [46] aligns with the findings of this study. Mir et al. [47] reported a corn starch swelling power ranging from 10.79 to 13.55 g/g, while Chandla et al. [48] found that amaranth starch had a swelling power ranging from 9.76 to 10.29 g/g. Quinoa starch's swelling power of 9.25 g/g [49] exceeded that of the present study. Swelling power enhances water absorption and improves food product texture, with an optimal range of 3 to 6.6 g/g [50]. Based on this, quinoa starch, quinoa, and amaranth flours can be used in food products where the reference corn starch is used.

Table 3. Functional properties

	Swelling power %	Solubility %	Oil absorption capacity (g/g)	WAI (g/g)	Water solubility %	Emulsion capacity %	Emulsion stability %
Quinoa starch	5.60 ±0.59^{a}	0.76 ±0.16^{a}	2.31 ±0.18^{a}	2.36 ±0.02^{a}	1.06 ±0.03^{a}	4.33 ±0.75^{a}	2.60 ±0.00^{a}
Amaranth starch	7.06 ±0.50^{b}	0.96 ±0.35^{a}	2.33 ±0.03^{a}	2.29 ±0.02^{a}	1.37 ±0.07^{a}	6.05 ±1.42^{a}	2.58 ±0.09^{a}
Corn starch	5.33 ±0.19^{a}	5.15 ±0.53^{b}	2.58 ±0.09^{a}	3.80 ±0.10^{d}	13.37 ±0.30^{d}	5.17 ±0.04^{a}	2.15 ±0.74^{a}
Quinoa flour	5.10 ±0.05^{a}	6.04 ±0.96^{b}	2.51 ±0.25^{a}	2.95 ±0.02^{c}	7.04 ±0.04^{c}	3.50 ±0.73^{a}	3.07 ±0.72^{a}
Amaranth flour	4.89 ±0.04^{a}	8.51 ±0.41^{c}	2.31 ±0.26^{a}	2.70 ±0.05^{b}	5.75 ±1.07^{b}	18.0 ±5.32^{b}	8.77 ±0.76^{b}

Values are means ± standard deviation; values with the same letter in a column are not significantly different (p > 0.05). n = 3. Solubility percentage is the amount of dry matter that remains soluble after boiling, and water solubility percentage is the dry matter that dissolves in water under standard conditions (room temperature -25°C).

Amaranth flour had the highest solubility percentage (Table 3). Corn starch and quinoa flour had a solubility that did not differ significantly (p>0.05), whereas those of quinoa and amaranth starches were significantly lower than those of corn starch. However, previous studies reported higher amaranth flour solubility [32,44] (see also Singh & Liu [35]). Mir et al. [47] reported a corn starch solubility of 9.54–10.42%, whereas Agustinisari et al. [51] recorded a range of 3.33–5.37%. In addition, a quinoa starch solubility of 4.9% was reported by Ramirez-Lopez et al. [27]. Soluble starches can replace fat, mimicking its mouthfeel and making products more appealing to consumers [30]. Therefore, like the reference corn starch, which may be used to replace fat, so can amaranth and quinoa starches.

3.4.2. Oil Absorption Capacity

All samples showed no significant differences in oil absorption capacity (p > 0.05) (Table 3). Thakur et al. [28] noted higher levels of quinoa flour than those found in this study, whereas Olawuni et al. [37] reported lower values. Jan et al. [19] reported a quinoa starch oil absorption capacity of 1.59 g/g, which is lower than the one reported in this study. Amaranth starch displayed a higher oil absorption capacity than the 1.86–1.93 g/g range reported by Chandla et al. [48], whereas Sindhu and Khatkar [32] recorded a 1.46 g/g oil absorption capacity lower than that in the current study. An oil absorption capacity of 1.5 to 2.5 g/g is reportedly useful in baked foods and meat products [52]. It could be suggested that quinoa and amaranth starches, along with amaranth flour, might be suitable for use in baked and meat products based on the specified range [52].

3.4.3. Water Absorption Index and Water Solubility Percentage

The WAI of starches and flours differed significantly (p < 0.05) (Table 3), with corn starch exhibiting the highest value. De Bock et al. [45] reported WAI values for amaranth flour ranging from 1.86 to 2.15 g/g, which are lower than those observed in this study. Coțovanu et al. [46] found a WAI of 2.50 g/g for quinoa flour lower than the current study value, whereas Olawuni et al. [37] reported 3.10 g/g, higher than the value in this study. Contreras-Jiménez et al. [34] reported a similar WAI of 2.36 g/g for quinoa starch. Chandla et al. [48] reported an amaranth starch value of 1.99 g/g and Sindhu and Khatkar [32] a value of 1.27 g/g, contrasting the 2.29 g/g reported in the current study. The higher WAI in quinoa and amaranth starch might be attributed to the protein content exceeding 2% since proteins possess strong water-binding capacities. Ideally, a WAI of 2.0 to 3.5 g/g is suitable for baking products and binders in meat products [52]. In the present study, quinoa and amaranth starch and flour fell within the ideal WAI range, making them suitable for use in meat and baked products.

The water solubility percentages of starches and flours differed significantly (p < 0.05) (Table 3), with corn starch having the highest solubility, followed by quinoa and amaranth flours. Thakur et al. [28] observed a 7.11% WSI for amaranth flour, higher than the one found in this study, whereas Coțovanu et al. [46] found a quinoa flour water solubility lower than that in this study by 2.0% value. Contreras-Jiménez et al. [34] reported a 4.56% WSI for quinoa starch, differing from the 1.06% reported in the current study. On the other hand, Rulahnia and Khatkar [49] reported a value of 1.13% for quinoa starch. Corn starch, as well as quinoa and amaranth flour, exhibited higher water solubility percentages than quinoa and amaranth starch, which might be owing to the lower protein content of the starches in comparison to the flour and corn starch.

3.4.4. Emulsion Capacity and Stability

The emulsion capacity of the starches and flours did not significantly differ (p > 0.05) (Table 3), except for amaranth flour, which had the highest emulsion capacity. The values in this study were higher than those reported by Vargas et al. [53] at 12.84% for amaranth flour. In this study, the amaranth grains used were cultivated in Southern Africa (Zimbabwe), whereas those used by Vargas et al. [53] were sourced from Colombia. Quinoa flour had a lower emulsion capacity than the 13.8% reported by Badia-Olmos et al. [54]. Amaranth and quinoa starch values did not differ from the corn starch value, and according to Omoregie [30], an emulsion capacity range of 60–80% maintains consistent product texture. However, the values for all samples in this study were below the range suggested by Omoregie [30], likely affecting product quality.

The emulsion stability values of flours and starches did not significantly differ except for amaranth flour ($p > 0.05$) (Table 3). Amaranth flour had an emulsion stability higher than the 7% reported by Tanimola et al. [41] and lower than the 45.39% reported by Olawaye and Gbadamosi [55]. Vicente et al. [56] reported an emulsion stability of 16.8% for quinoa flour, which is higher than that in the present study. Amaranth and quinoa starch emulsion stability values were close to the reference corn starch, which might suggest the possible use of the amaranth and quinoa water-extracted starches in emulsion products.

The functional properties of corn starch, including its WAI, swelling power, OAI, and emulsion capacity, make it a valuable ingredient in baked goods. These properties contribute to improved texture and moisture retention, ultimately enhancing the overall quality of extruded snacks and breakfast cereals. Corn starch has been used in emulsified products like sausages or meatballs to improve emulsion stability, water, and oil retention. In bakery fillings, corn starch has been used to create smooth and stable fillings by absorbing water and maintaining consistency. Corn starch has also been used in plant-based milk or yogurt, where it aids emulsification and provides a creamy texture. In battered and breaded foods, it has improved oil absorption and helps achieve a crispy texture in fried items. Therefore, based on the results of the current study, quinoa starch, quinoa flour, amaranth starch, and amaranth flour can be used as alternatives in those products because their functional properties did not differ significantly from corn starch in most functional properties.

4. Conclusions

The proximate composition of water-extracted starch was similar to the literature values for quinoa and amaranth starches obtained via alkali methods, with the exception of protein content, which was higher in the hydro-extracted starches. Quinoa, amaranth, and corn starches had no significant difference in their functional properties. This suggests the potential use of these starches in meat products as thickeners and binders, while flours are better suited for baked goods because of properties such as WSI and water absorption capacity, which were significantly higher than those of the starches. Functional properties, including the WAI, swelling power, and emulsion capacity, were not significantly impacted by the extraction method. However, swelling power was higher in the starches, which is beneficial for baking and meat products. The WAI for both the flours and starches falls within the recommended range of 2-3.5 g/g, thereby ensuring optimal functionality in various products.

Technological properties, such as porosity, which influence oil uptake, were comparable in both flours and water-extracted starches and were also similar to commonly used corn starch. This makes the water-extracted starches suitable for products like fried sausages. Quinoa and amaranth starches extracted using water only have the potential to be used in other industries, such as pharmaceuticals, where moderate protein content is required.

Pending investigations on the performance of the Quinoa and Amaranth flours and solvent-free extracted starches' technological and functional properties in a real-life food system, it suffices to mention that the findings of this study clearly suggest potential commercial applications for quinoa and amaranth starch as alternatives to corn starch. These starches could be utilized in a variety of products, including gravies, puddings, custards, sausages, and meatballs, as effective binders. Additionally, they may serve as coatings for fried foods, thickening agents in soups, and ingredients in baked goods like bread, offering promising versatility in food industry applications. They may also be used in the pharmaceutical industry where corn starch has been incorporated as a binder in tablet formulations, as a coating of tablets, and stabilizer of emulsions in some pharmaceutical formulations.

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