International Journal of Food Studies | IJFS 2025 | Volume 14 | pages 170–185

Effect of Quinoa and Amaranth Starches as Fat Replacers on the Technological Properties and Quality of Fresh, Fermented, and Emulsion Beef Sausages

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Received: 17 September 2026; Published online: 9 February 2026

Abstract

Sausages, a global favorite, generated $6 billion in African market revenue in 2018, but their reliance on animal fat poses health risks relating to diabetes and cardiovascular diseases. This study explores quinoa and amaranth starches as climate-resilient alternatives to corn starch in fresh, fermented, and emulsion sausages. Starch was extracted via wet milling using water, sieving, and centrifugation, while sausages were formulated with fat replacers at 3% and 10% inclusion levels. Technological property analysis included water-holding capacity (WHC), cooking loss, pH, and emulsion stability, and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity was used to evaluate antioxidant activity. Higher fat replacer levels reduced cooking loss, with quinoa starch excelling in fresh sausages and amaranth starch performing best in fermented and emulsion sausages. WHC was superior at 10% inclusion, particularly for fresh and emulsified sausages. Quinoa starch showed strong antioxidant activity at lower levels, while higher inclusions enhanced benefits in emulsion sausages. These starches proved promising alternative fat replacers, offering health and shelf-life benefits in sausage formulations.

Keywords: Sausage reformulation; Fat replacement; Plant-based starches; Health-oriented sausages; Sausage quality

1 Introduction

Processed meats such as burgers and sausages are consumed in different and diverse cultures worldwide (Rinaldoni et al., 2014). According to statistics reported by IndexBox (2019), in Africa, the sausage market revenue was $6 billion in 2018. Sausages are made through the process of grinding and mincing the muscle tissues and mixing them with animal fat, salt, herbs and spices, and other non-meat ingredients (e.g., binders) that may be added to improve their quality (Belitz et al., 2009). The inclusion of animal fat poses risks relating to life-threatening diseases such as type 2 diabetes, obesity, cancer, and cardiovascular diseases (Botella-Martínez et al., 2023). To inter alia minimise these risks, the World Health Organisation (WHO) limits

 10.7455/ijfs/14.01.2025.a10

the consumption of saturated fats to 10% and encourages replacing them with plant sources (World Health Organization, 2023).

In the pursuit of healthier food products, the use of fat replacers has gained considerable traction within the food industry, particularly in applications such as ice cream and margarine, where starches have been employed to substitute fat (Chen et al., 2020). However, this concept has yet to be widely adopted in the meat industry. Effective fat replacers must replicate the functional attributes of fat, such as texture, mouthfeel, and structural integrity, without compromising product quality or consumer acceptance. While binders have long been incorporated into meat formulations to enhance texture and functionality, they have not been explicitly utilized as fat replacers. Nevertheless, ingredients like starch possess technological properties that make them promising candidates for fat replacement in meat products.

Corn starch, soya protein, and non-fat dried milk have been utilised as binders in sausages. Binders are used to enhance the stability of the product. They tend to bind with water, thereby strengthening the emulsifier ability of meat to form stable emulsions (Sembor et al., 2023). This improves the cooking yield and WHC. However, consumer allergies to soya protein and non-fat dried milk have been reported (Johnson et al., 2022), hence the need for alternative binders and fat replacers. Quinoa and amaranth are climate-smart crops that can give higher yields even under harsh climatic conditions (Bazile, 2023) and have been used in the food industry. While their flours can be used as alternative binders in sausages (Muchekeza et al., 2021), their water-extracted starches have not been studied in the different types of sausages, either as binders or fat replacers. Water-extracted starches can be regarded as healthy since they do not have chemical residues, unlike those commonly obtained using chemical reagents, such as via the alkali steeping method.

Quinoa and amaranth have been used in the manufacture of different food products, such as baby foods, beer, bread, and biscuits (Balakrishnan & Schneider, 2022), but using their starches in meat products has received limited attention in the literature. Park et al. (2021) included quinoa starch and flour in chicken meatballs and tested for the physicochemical (cooking loss, water holding capacity, pH, and emulsion stability) and textural properties that were affected by the inclusion. Their results showed a reduction in cooking and drip losses. Baioumy et al. (2018) incorporated quinoa flour in beef burgers and analysed the nutritional composition and sensory effect. Consumers acceptance of the beef burgers with quinoa flour, was within a range of 8.0 to 9.0, which was rated good to excellent on a scale of 0 to 10. Additionally, Verma et al. (2019) tested goat nuggets made with both quinoa and amaranth flours, and their inclusion improved the technological properties and produced nuggets that were acceptable to consumers.

There is, however, no literature on the use of quinoa and amaranth water-extracted starches in sausages. This study seeks to examine whether quinoa and amaranth starches and flours can serve as effective fat replacers in fresh, fermented, and emulsion sausages. Fresh sausages are uncooked and are made from raw meat. Fermented sausages are known for their tangy flavour resulting from the fermentation process. The emulsion-type sausages are finely ground and smooth, cooked, and ready to eat, such as bologna. This study, therefore, investigated the effect of using quinoa and amaranth water-extracted starches on the physicochemical and antioxidant properties of fresh, fermented, and emulsion sausages in comparison to reference corn starch and their grain flours. Emulsion stability was also tested on emulsion sausages specifically.

2 Materials and Methods

2.1 Raw materials

Corn starch (reference) was sourced from WFM Starch Products Company, South Africa. Amaranth flour and quinoa grains were acquired from Four Season Foods Company, Zimbabwe, in 2024.

2.2 Starch extraction

The extraction of quinoa and amaranth starches was carried out following a modified method of Jan et al. (2017). A ratio of 1:6 for flours to water was prepared and left at 4^{o}C for 24 hours in a shaking incubator (Bio base -BJPX-100B). Mixtures were wet milled for 2 minutes using a laboratory blender, and they were passed through 250 μm, 75 μm, and 45 μm sieves. The filtrate from the sieving was centrifuged (Bio base -BKC-TH16) at 5500 rpm for 15 minutes. The supernatant was discarded from the centrifuge tubes, and a yellowish layer above the starch cake was removed. The starch cake was suspended in water four times and centrifuged after each suspension (4 times). The starch was left to dry at 40^{o}C for a total of 12 hours in an oven (Scientific South Africa-225) and stored in sealed plastic containers at room temperature until analysis.

2.3 Sausage formulation

Fresh sausage

Five binders and fat replacers (corn starch, quinoa flour, amaranth flour, quinoa starch, and amaranth starch) were incorporated into sausage formulations at 3% and 10% inclusion levels. Minced meat was combined with salt (2%), fat (10%), cold water (5%), and the respective binders, following FAO guidelines for 3% inclusion and literature-based standards for 10% inclusion (Dautova et al., 2024; ÖZER & Secen, 2018). Mixing was followed by stuffing into casings using a model CV-3 sausage filler. The sausages were stored in plastic bags under refrigeration prior to analysis (Table 1).

Fermented sausage

Sausages were formulated with five binders and fat replacers (corn starch, quinoa flour, amaranth flour, quinoa starch, and amaranth starch) incorporated at 3% and 10% levels, based on FAO standards and prior studies (Dautova et al., 2024; ÖZER & Secen, 2018). Minced meat was prepared using a Reber mincer (Model 9504NSP/SF), followed by the addition of salt (2%), fat (10%), cold water (5%), and fat replacers. The mixture was homogenized and stuffed into casings using a model CV-3 sausage filler. Fermentation was conducted at 32 ± 1 ^{o}C and 90% relative humidity for 36 hours in a controlled incubator (LRHS-150, Yuejin Medical Apparatus Co., Ltd., Shanghai, China). Post-fermentation, samples were refrigerated until further analysis (Table 2).

Emulsion sausage

Beef meat from the round and shank portions, along with beef fat, was procured within 24 hours post-mortem. The fat was ground separately using a TRE SPADE Tritanarne 22 220/50 mincer at 1400 rpm and stored at -20 ^{o}C until use. Emulsion-type sausages were prepared following a modified protocol from Pereira et al. (2019) with formulations detailed in Table 3. Replications were conducted over three consecutive days. Five binders and fat replacers (corn starch, quinoa flour, amaranth flour, quinoa starch, and amaranth starch) were incorporated at 3% and 10% inclusion levels, based on FAO guidelines and prior studies (Dautova et al., 2024; ÖZER & Secen, 2018). Meat was chopped and ground using the TRE SPADE mincer, then transferred to a DAMPA cutter (Model CT 50N) and chopped for 3 minutes with salt and half of the ice-water mixture. Subsequently, beef fat, remaining ice-water, fat replacers, and spices were added and chopped for an additional 3 minutes at high speed, maintaining mixture temperatures below 10 ^{o}C. Raw batter samples (100 g) were stored in plastic bags at 4 ^{o}C for analysis. Additional batter portions were shaped into rolls, wrapped in plastic, and refrigerated for 24 hours. These rolls were then unwrapped, placed on oven trays, and baked at 150 ^{o}C for 1 hour, turning after 30 minutes. Baked samples were cooled to room temperature and refrigerated until use.

Table 1: Ingredients of the fresh sausage recipe

Ingredients	**Fat replacer (%)**		**Mixed spice (%)**	**Water (%)**	**Salt (%)**	**Fat (%)**	**Beef flanks and trimmings (%)**
Corn starch	3	–	1.5	4	1.5	10	80
	–	10	1.5	5	2	3	80
Quinoa starch	3	–	1.5	4	1.5	10	80
	–	10	1.5	5	2	3	80
Amaranth starch	3	–	1.5	4	1.5	10	80
	–	10	1.5	5	2	3	80
Amaranth flour	3	–	1.5	4	1.5	10	80
	–	10	1.5	5	2	3	80
Quinoa flour	3	–	1.5	4	1.5	10	80
	–	10	1.5	5	2	3	80

Recommendation of the FAO (1985) on fresh sausage making.

Table 2: Ingredients of the fermented sausage recipe

Ingredients	**Fat replacer (%)**		**Mixed spice (%)**	**Water (%)**	**Starter culture (%)**	**Salt (%)**	**Sucrose (%)**	**Fat (%)**	**Beef flanks and trimmings (%)**
Corn starch	3	–	0.6	5	0.2	1.6	1.6	10	78
	–	10	0.6	5	0.2	1.6	1.6	3	78
Quinoa starch	3	–	0.6	5	0.2	1.6	1.6	10	78
	–	10	0.6	5	0.2	1.6	1.6	3	78
Amaranth starch	3	–	0.6	5	0.2	1.6	1.6	10	78
	–	10	0.6	5	0.2	1.6	1.6	3	78
Amaranth flour	3	–	0.6	5	0.2	1.6	1.6	10	78
	–	10	0.6	5	0.2	1.6	1.6	3	78
Quinoa flour	3	–	0.6	5	0.2	1.6	1.6	10	78
	–	10	0.6	5	0.2	1.6	1.6	3	78

Table 3: Ingredients of the emulsion sausage recipe

Ingredients	**Fat replacer (%)**		**Mixed spice (%)**	**Ice (%)**	**Sugar (%)**	**Sea salt (%)**	**Fat (%)**	**Beef flanks and trimmings (%)**
Corn starch	3	–	0.5	15	0.7	0.8	12	68
	–	10	0.5	15	0.7	0.8	5	68
Quinoa starch	3	–	0.5	15	0.7	0.8	12	68
	–	10	0.5	15	0.7	0.8	5	68
Amaranth starch	3	–	0.5	15	0.7	0.8	12	68
	–	10	0.5	15	0.7	0.8	5	68
Amaranth flour	3	–	0.5	15	0.7	0.8	12	68
	–	10	0.5	15	0.7	0.8	5	68
Quinoa flour	3	–	0.5	15	0.7	0.8	12	68
	–	10	0.5	15	0.7	0.8	5	68

2.4 Measurement of technological properties and quality of sausages

Water-holding capacity

Water-holding capacity (WHC) of the sausage samples was assessed following the method of Oliveira et al. (2021), with minor modifications. Approximately 2.0 g (± 0.10) of each sample was placed on filter paper and subjected to a 10 kg cylindrical weight for 5 minutes. The filter paper was weighed before and after pressing, and WHC was calculated based on the change in weight as shown in equation 1.

$$WHC(\%) = 100\text{–Free water} \tag{1}$$

Cooking loss

Cooking losses were evaluated of sausage samples formulated with five fat replacers: amaranth flour, quinoa flour, amaranth starch, quinoa starch, and corn starch. Each sample, weighing 10 g or more, was subjected to deep-fat frying in sunflower oil for 6-10 minutes and was turned every 3 minutes to prevent over-browning. The weight of the raw emulsion sausage was recorded before and after cooking, and cooking losses were calculated as the difference in weight.

pH

Each 5 g of raw batter and cooked sausage samples was homogenised with 20 mL of distilled water. The pH of the sausage samples was determined with a pH metre (Model 340, Mettler-Toledo GmbH, Switzerland). The analysis was carried out in triplicate (Lee et al., 2017).

Emulsion stability

Emulsion stability of the sausage samples was assessed following the method of Rosero Chasoy and Serna Cock (2017), with slight modifications. A 20 g portion of sausage emulsion was placed in centrifuge tubes and heated in a water bath at 80 ^{o}C for 30 minutes. After cooling at room temperature for 20 minutes, the volumes of released water and fat were measured, and emulsion stability was calculated as follows:

$$E_s(\%) = \frac{W_{\text{AD}}}{W_{\text{BH}}} \times 100 \tag{2}$$

where E_s is the emulsion stability (W_{AD} is the meat emulsion weight in the tube after draining the lipid layer, and W_{BH} is the meat emulsion weight in the tube before heating.

DPPH scavenging activity

The capacity of extracts to scavenge free radicals (2,2-diphenyl-1-picrylhydrazyl, DPPH) was determined using a method outlined by Gaytán-Martínez et al. (2017). A standard solution of vitamin C was prepared at a concentration of 60 micrograms per milliliter (μg/mL) for analytical calibration. The free radical scavenging ability was calculated using equation 3 as suggested by Sompong et al. (2011):

$$\text{Scavenging activity}(\%) = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times 100 \tag{3}$$

where A is the absorbance measured at 515 nm, A_{control} is the absorbance of the DPPH solution without extract, and A_{sample} is the absorbance of the DPPH solution with extract.

3 Results and Discussion

3.1 Fresh sausage cooking loss

There was a significant difference (p<0.05) in cooking loss of the fresh sausages that were made with the inclusion of corn starch, quinoa, amaranth flour, and starches (Figure 1). Moreover, the cooking loss of all the sausages decreased with an increase in the inclusion level of the starches and the flours. In comparison to the reference (corn starch), quinoa and amaranth starches were better at a three percent inclusion level as a fat replacer in terms of cooking loss. Corn starch had the highest cooking loss among the starches and flours at 3%. It was even better than amaranth starch and flour at a 10% inclusion level. In this study, we could conclude that quinoa starch is a better alternative to corn starch since it had the lowest cooking loss at both levels of inclusion in fresh sausages. Cooking loss in the sausages could have been influenced by the different water-binding abilities (Verma et al., 2019) of the starches and the flours.

3.2 Fermented sausage cooking loss

Fermented sausages (Figure 2) had significantly different ($p<0.05$) cooking losses for quinoa starch, quinoa flour, amaranth starch, amaranth flour, and corn starch at 3% and 10% inclusion levels. Sausages with quinoa and amaranth starch had lower cooking loss than the reference (corn starch), which was also higher than the cooking losses of sausages with quinoa and amaranth flours at the two inclusion levels. The cooking loss, which was lower in sausages with quinoa and amaranth starch, was due to moisture retention by the starches and stabilization of the meat mixture by forming a gel matrix that traps both fat and moisture, thereby preventing leakages during cooking. The motion is supported by Totosaus (2009). However, there is also a contribution of protein coagulation due to lowered pH that is enhanced by fermentation, thereby retaining water and reducing cooking loss (El-Ghorab et al., 2014; Osman & Sulieman, 2022).

3.3 Emulsion sausage cooking loss

Cooking loss reduced significantly ($p<005$), with an increase in the starch or flour levels in the emulsion sausages (Figure 3). In emulsion sausages, the corn starch (reference) sample had the highest cooking loss compared to the sausages that were made of quinoa, amaranth starches and flours. Therefore, regarding cooking loss, the other samples can be used as alternatives to corn starch since they had less cooking loss, which is desirable. Emulsion formation helps prevent cooking loss if done properly, and the emulsion will be stable.
Cooking loss was tested in beef burgers with quinoa flour at levels of 2.5% and 10%. The cooking loss at the lower level (25.1%) was higher than at the higher level (16.43%) (Baioumy et al., 2018), which agrees with the results in this study for all the types of sausages, where 10% had a lower cooking loss than 3%. Amaranth flour was analyzed for cooking loss in fresh beef sausages by Sharoba (2009), and the cooking loss was 10.08%, which is lower than the values that were reported in the current study. The difference is due to other ingredients that were included by Sharoba (2009) such as starch at 4.65%, dried skim milk, and sodium pyrophosphate, which influence water binding that improves cooking yield, thereby reducing cooking loss.

3.4 Water-holding capacity

Significant differences were noted in the WHC ($p < 0.001$) of fresh sausages (Figure 1) formulated with corn starch, quinoa starch, amaranth starch, quinoa flour, and amaranth flour. Similarly, fermented sausages and emulsion sausages exhibited significant differences ($p < 0.001$) for all samples.
The WHC of fresh sausages made with quinoa and amaranth starch at a 10% inclusion level was higher than that with corn starch inclusion. These findings suggest that quinoa and amaranth starch can serve as effective alternatives to corn starch in fresh sausages, as high WHC positively influences the texture and quality of the sausages (Wang et al., 2009). At the 3% inclusion level, the WHC results for quinoa starch, amaranth starch, and corn starch were comparable. However, the flours at 3% inclusion level exhibited lower WHC compared to quinoa starch, except for amaranth flour at 10%, while quinoa flour recorded the lowest WHC among all samples. The WHC of fresh sausages in the current study was lower than the values reported by Shaat et al. (2020), where 10% quinoa flour achieved a WHC of 75.3%. Additionally, quinoa starch demonstrated a better WHC compared to the reference corn starch. A high WHC is associated with the formation of gel-like matrices that trap water in the starches (Kudryashov & Kudryashova, 2023). The results are also better than the flours' WHC, which might explain why the starch interactions were better than protein-water interactions (Kudryashov & Kudryashova, 2023).
In fermented sausages, there was no significant

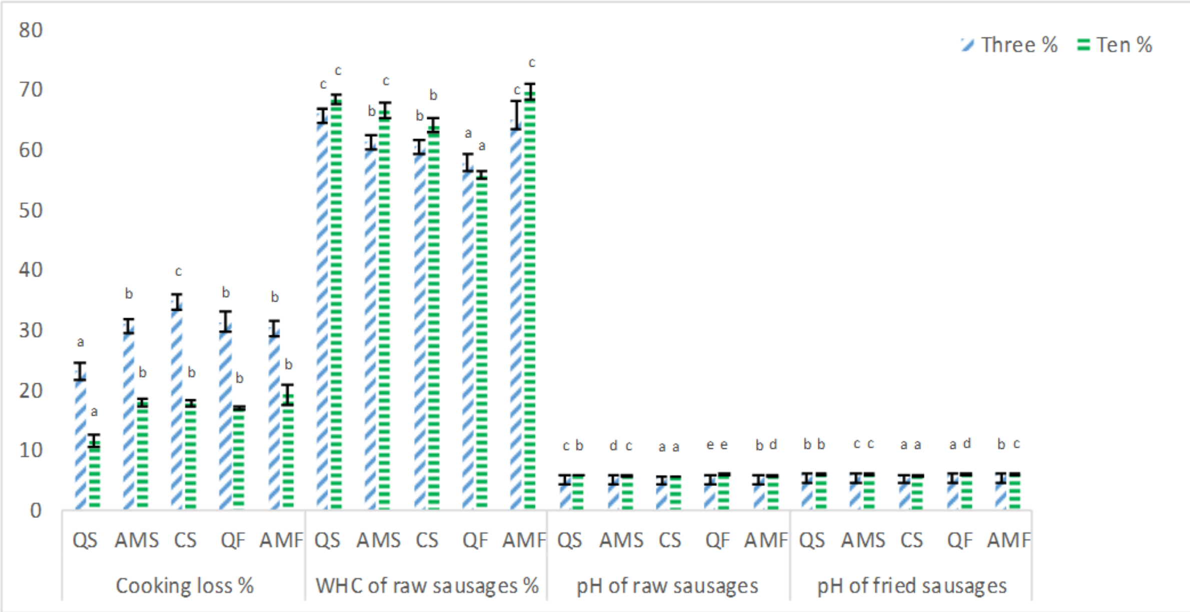

Figure 1: Fresh sausages' technological properties. QS-Quinoa starch, AMS-Amaranth starch, CS- Corn starch, QF-Quinoa flour, and AMF-Amaranth flour

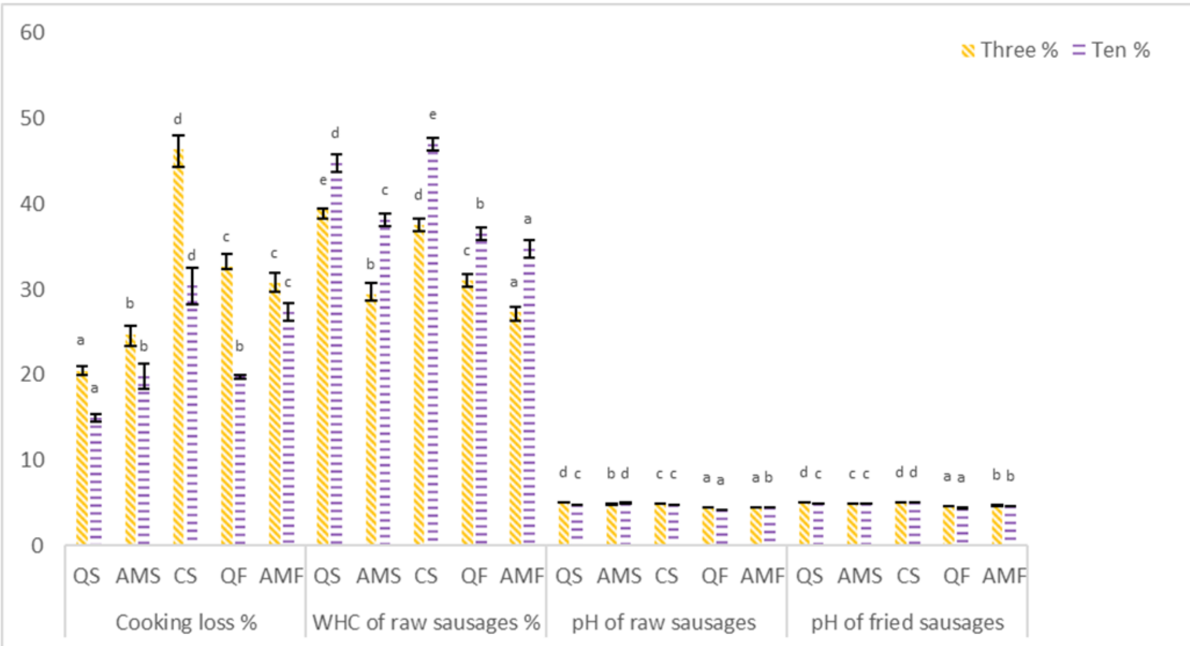

Figure 2: Fermented sausages' technological properties. QS-Quinoa starch, AMS-Amaranth starch, CS-Corn starch, QF-Quinoa flour, and AMF-Amaranth flour

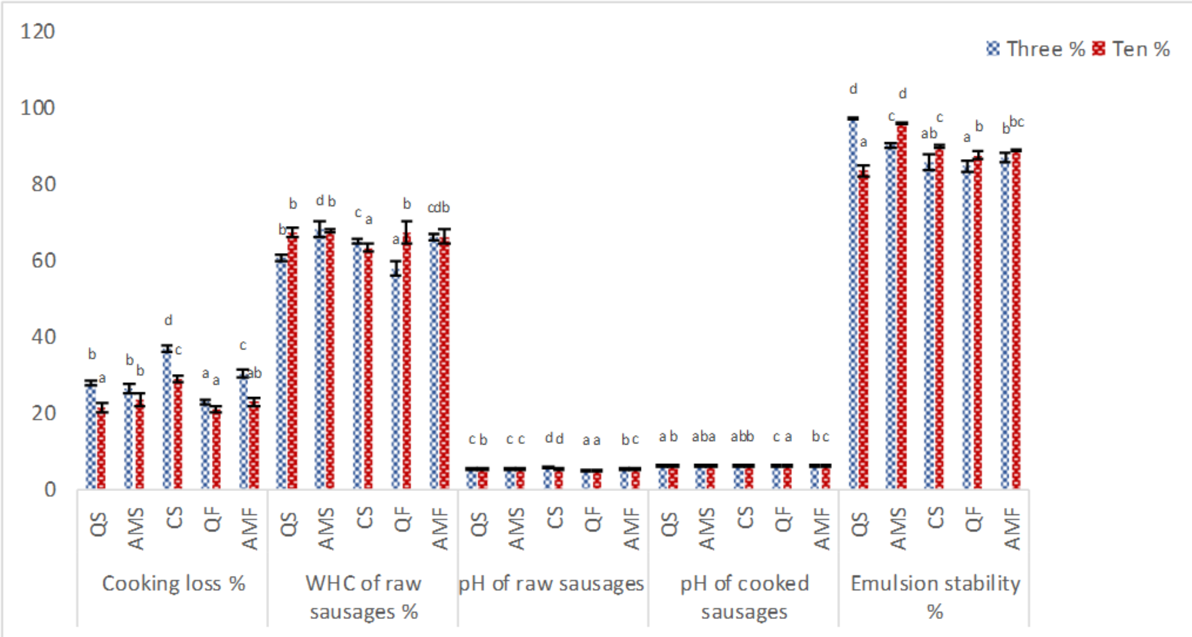

Figure 3: Emulsion sausages technological properties. QS-Quinoa starch, AMS-Amaranth starch, CS-Corn starch, QF-Quinoa flour, and AMF-Amaranth flour

difference (p<0.001) (Figure 2) in the flours and starches at both levels of inclusion (3% and 10%). Amaranth flour had the lowest WHC, followed by amaranth starch and quinoa flours. Moreover, quinoa starch was the only sample that was observed to have a WHC higher than that of corn starch at a 3% inclusion level in this study. This indicates that quinoa starch is a promising alternative to corn starch for fermented sausages, particularly at the 3% inclusion level. All the samples exhibited lower WHC, which is below 50% in fermented sausages for both 3% and 10% inclusion levels. The decrease in pH lowered WHC by denaturing proteins and reducing their ability to bind water. While starches help maintain the gel matrix, results for sausages with flours were even lower because they contain more proteins than starches (Lücke, 2000).

In emulsified sausages made with quinoa starch, amaranth starch, quinoa flour, amaranth flour, and corn starch, significant differences in WHC ($p < 0.001$) were observed (Figure 3). At the 3% inclusion level, amaranth starch exhibited the highest WHC, followed by amaranth flour, both outperforming corn starch as the reference fat replacer. Quinoa flour had the lowest WHC, followed by quinoa starch. These results suggest that amaranth starch or flour could serve as better alternatives to corn starch in emulsified sausages at 3% inclusion levels. At the higher inclusion level of 10%, corn starch had the least WHC, with the samples ranking as follows: amaranth starch > quinoa flour > quinoa starch > amaranth flour > corn starch. Nevertheless, amaranth starch consistently showed the highest WHC among all samples, supporting its recommendation as an alternative fat replacer for emulsified sausages at both inclusion levels. WHC for corn starch decreased as the inclusion level increased.

Dautova et al. (2024) noted WHC values at 10% for emulsified sausages with quinoa seed flour were 78.68%, which surpassed the results (67.1%) observed in this study. Jairath et al. (2017) reported a WHC of 53.36% for corn starch at 3%, which increased when inclusion was increased to

9% for beef sausages, which contrasts with the results of this study, where WHC was higher at 3% inclusion for both amaranth starch and corn starch.

The WHC was greater in emulsified sausages than in fresh and fermented sausages, likely due to the principle outlined by Wang et al. (2009), which states that smaller particles increase the surface area available for water interaction, thereby enhancing WHC. Fine comminution of meat and ingredients exposes proteins and starches, facilitating stronger binding and forming a more stable matrix that traps water and fat.

3.5 Potential of hydrogen (pH)

No significant difference ($p < 0.001$) was observed in pH values between raw and cooked fresh sausages (Figure 1) across all samples, including quinoa starch, amaranth starch, quinoa flour, amaranth flour, and corn starch. For raw fresh sausages, pH values tended to increase toward neutrality or alkalinity for most samples as the inclusion level increased from 3% to 10%, except for quinoa starch, which exhibited a slight increase in acidity from 5.8 to 5.78.

Quinoa flour showed pH values closer to neutrality compared to other samples at both the 3% and 10% inclusion levels. The pH behaviour of the reference corn starch and amaranth starch was similar, with values remaining consistent at 3% and 10%. Increasing fat replacer inclusion levels shifted pH toward neutrality. However, all pH values fell within the recommended range of 5.3-6.2 (Luong et al., 2022), ensuring optimal texture, flavour, and microbial stability in fresh meat products (Toldrá & Reig, 2011).

Cooked fresh sausages made with quinoa and amaranth flour showed pH increases from 5.95 to 6.11 and 6.00 to 6.08, respectively, due to protein-water interactions described by Babatunde et al. (2013), leading to the release of other basic compounds such as amino acids, alkaline phosphates, and hydroxyl ions. The authors also attributed this effect to flour buffering capacity, which resists acidic changes during cooking. The pH levels were the same at 3% and 10% corn starch inclusion levels, and the trend was the same for quinoa and amaranth starch. This might be due to starch gelatinisation, which does not significantly alter pH levels, but primarily improves texture. The pH levels for all samples did not exceed 6.2, which could result in undesirable texture, off-flavours, and compromised product safety (Toldrá & Reig, 2011). Considering the results of this study, quinoa and amaranth starches and flours be used as alternatives to corn starch, although quinoa and amaranth starches in sausage formulations are recommended, considering their favourable pH profiles, which are important for shelf life, colour, WHC, and texture in meat products.

Verma et al. (2019) observed a similar pH trend, increasing from raw sausage to cooked sausage values in goat nuggets made with amaranth and quinoa flour at a 3% inclusion level, aligning with the findings of this study. However, their pH values for raw and cooked products were higher (6.37) than those reported here. At a 10% quinoa flour inclusion level, the pH of beef burgers was 6.98 (Baioumy et al., 2018), which is higher than the value reported in this study. Shaat et al. (2020) reported a pH of 5.78 for beef sausages made with quinoa flour, which closely matches the results of this study. In contrast, Sharoba (2009) reported a pH of 5.94 for sausages with 10% amaranth flour inclusion, slightly exceeding the values observed in the current study for raw fresh sausages.

There was no significant difference ($p < 0.001$) in the pH values of raw and cooked fermented sausages (Figure 2) across all samples (quinoa starch, amaranth starch, quinoa flour, amaranth flour, and corn starch). In raw sausages, the pH values were higher at the 3% inclusion level compared to the 10% inclusion level for most samples, except amaranth starch. Quinoa starch demonstrated a pH value higher than the reference corn starch at the 3% inclusion level. At 10% inclusion, the pH values of corn starch and quinoa starch were equivalent.

Quinoa and amaranth starch resulted in pH values within the recommended range of 4.6-5.3 for fermented sausages, as suggested by Holck et al. (2017). This implies that both amaranth starch and quinoa starch could serve as viable alternatives to corn starch in fermented sausages, particularly at lower (3%) inclusion levels and 10% inclusion levels for quinoa starch. However, quinoa and amaranth flour exhibited pH values below the recommended range (4.6-5.3) at inclusion levels of 10%, indicating its suitability for fermented sausages only at the 3% inclusion level.

At 3% inclusion, the pH values for fermented cooked sausages were consistent between quinoa starch and corn starch and were higher than those for amaranth starch, amaranth flour, and quinoa flour. Quinoa flour exhibited the lowest pH value at both 3% and 10% inclusion levels, followed by amaranth flour. Microbial activity is enhanced during fermentation due to the presence of essential amino acids, which stimulate metabolic processes, as noted by Madigan et al. (2018). They reported the need for amino acids for the growth of microorganisms.

For cooked fermented sausages, at the 10% inclusion level, the pH values were lower than those at the 3% inclusion level. This reduction in pH could be due to increased microbial activity at higher inclusion levels due to sufficient or greater provision of nutrients for the microorganisms. Corn starch pH did not decrease with an increase in inclusion level; instead, it increased slightly. Quinoa and amaranth starch displayed slight pH reductions as the inclusion level increased, thereby leading to a recommendation that they may be used in fermented sausages as alternatives to corn starch. The recommendation is supported by the fact that the pH of raw sausages remained within the range of 4.6-5.3, effectively inhibiting the growth of pathogenic bacteria (Liu et al., 2024).

The pH values of raw emulsion batter (Figure 3) were not significantly different for all the inclusion levels, $p=0.386$. However, the pH between the samples had a significant difference ($p< 0.001$). The same trend occurred for cooked emulsion sausages, which had no significant difference in pH in the inclusion levels but had a significant difference ($p<0.001$) in pH between the samples. The pH values of raw emulsion sausage batter were in the following order: CS>AMS>QS>AMF>QF. Corn starch (reference) had the highest pH at both 3% and 10% inclusion levels. The order changed at 10% to CS>AMS>AMF>QS>QF, where quinoa starch and flour were at the lower end of the pH values. The pH values fell in the recommended range of 45.3 to 6.2 (Luong et al., 2022) for all samples. Therefore, quinoa starch and flour and amaranth starch and flour, at both inclusion levels (3% and 10%), can be used as alternatives to corn starch in emulsion sausages when considering pH, with amaranth starch and flour having pH values slightly nearer to the reference.

In cooked sausages at 3% inclusion, the pH values were consistent for all the samples, with amaranth starch having the same value as corn starch. The pH values increased for quinoa starch, corn starch, and amaranth flour-based emulsion sausages at a 10% inclusion level. This increase is due to the dilution of acidic pH caused by the presence of neutral starches, which generally do not alter the pH of the product (Luong et al., 2022). The change in values towards neutrality might also be owing to their water-binding capacity, which increases pH because of the water. The proteins in the amaranth flour might also have increased pH because of their buffering capacity, as affirmed by Tripathi et al. (2019). The pH value decreased for both amaranth starch and quinoa flour at the 10% compared to the 3% inclusion level. Lowering the pH for amaranth starch may be due to interaction with meat proteins, thereby potentially altering ionic balance and releasing hydrogen ions (Ianiţchi et al., 2023). Like starch in behaviour, quinoa flour proteins and starch may interact with meat proteins in emulsions, thereby releasing hydrogen ions.

Considering the pH values in cooked emulsion sausages. Quinoa starch and flour and amaranth starch at both inclusion levels (3% and 10%) and amaranth flour at 3% inclusion can be used as alternatives to corn starch but not amaranth flour at 10% inclusion, which resulted in a pH above the recommended value of 6.2 for the inhibition of microorganisms. Dautova et al. (2024) reported the pH values of emulsion sausages were lower than 6.63 at 10% inclusion of quinoa flour. Emulsion sausages were also made, and when cooked, the pH value recorded was lower (5.94) than the values recorded in this study (Öztürk-Kerimoğlu et al., 2020).

3.6 Emulsion stability

The emulsion stability of sausage (Figure 3) with inclusion levels of 3% and 10% had no significant difference ($p=0.546$). However, the five samples had a significant difference ($p<0.001$). Quinoa starch had the highest emulsion stability, followed by amaranth starch, amaranth flour, and corn starch. Quinoa flour had the lowest emulsion stability value at 3% inclusion levels in the emulsion sausages. The values were not in the same order at the 10% inclusion level. Amaranth starch had the highest emulsion stability, followed by the reference corn starch, amaranth flour, quinoa flour and quinoa starch with the least. This phenomenon occurs because certain starches, such as quinoa starch, function as effective stabilizers at lower inclusion levels (Dautova et al., 2024). However, excessive amounts can lead to over-thickening, which disrupts the emulsion structure and reduces stability by preventing the uniform dispersion of fats and water within the system (Ombonga et al., 2024). An increase in the emulsion stability was exhibited by all the other samples, including corn starch, because at lower inclusion levels, a fat replacer such as corn starch might not be sufficient to form a stable network that binds water and fat. Therefore, a better emulsion stability value might be achieved at higher inclusion levels. This aligns with a report by Saari et al. (2019) on the role of starches in stabilising emulsions. The explanation also applies to flours because they have starch as a major component.

Jairath et al. (2017) reported emulsion stabilities of 87.26% and 93.12% for emulsion sausages that were made with an inclusion of 3% and 9% corn starch, respectively. These results were higher than the emulsion stability reported in this study for corn starch at 3% and 9% inclusion. The results allow us to consider quinoa starch and amaranth starch as alternatives for corn starch at both inclusion levels when making emulsion sausages with a fat replacer because they have a higher emulsion stability. Quinoa starch could be used best at 3% inclusion and amaranth starch at 10% inclusion to achieve emulsion stabilities higher than with corn starch inclusion.

3.7 DPPH scavenging activity

The DPPH scavenging activity of the samples in the different types of sausages (emulsion, fresh, and fermented) was significantly different ($p<0.05$) (Table 4). Fresh sausages made with quinoa starch (3%), corn starch (3%), quinoa flour (3%), amaranth flour (3%), amaranth starch (10%), and quinoa flour (10%) had no significant difference in terms of DPPH scavenging activity. In comparison, amaranth starch (3%), quinoa starch (10%), corn starch (10%), and amaranth flour (10%) had no significant difference ($p>0.05$).

Fresh sausages made with corn starch at a 3% level had the lowest DPPH scavenging activity amongst all samples, followed by quinoa flour sausages at 10% inclusion levels. Due to the higher values of other samples than corn starch at 3% and considering the benefits of DPPH scavenging activities, which include contribution to oxidative stability in food products, they may be used as alternatives to corn starch in sausages to improve antioxidant activity. The high levels of antioxidants, as predicted by the DPPH scavenging activity, help in the prevention of the effects of free radicals in human metabolism at the deterioration of fatty foods, as affirmed by Gulcin and Alwasel (2023), thereby improving shelf life. When flours and starches were included at a 10% level, corn starch had the highest value, followed by quinoa starch, and the quinoa flour had the lowest value. However, because they all had no significant difference ($p>0.05$) except for quinoa flour, which was significantly different ($p<0.05$), the flours and starches at a 10% inclusion level may be used as an alternative to corn starch considering the benefits of DPPH scavenging to improve antioxidant capacity. In general, scavenging activity values were higher in sausages made with a 10% inclusion level than in a 3% inclusion level, which is acceptable since the concentration of the antioxidants will have increased.

The DPPH scavenging activity values for fermented sausages with an inclusion level of 3% were higher in sausages with quinoa starch in the following order: QS>CS>QF>AMS>AMF. Quinoa starch had the highest value, which was significantly ($p<0,05$) different from other samples, and amaranth flour had the lowest value.

Table 4: DPPH scavenging activity in sausages

Sample	Fresh sausages	Fermented sausages	Emulsion sausages
Quinoa starch (3%)	88.28±0.18^{a}	88.07±0.05^{c}	90.46±0.41^{c}
Amaranth starch (3%)	88.71±0.40^{b}	87.16±0.34^{b}	91.76±0.10^{d}
Corn starch (3%)	87.39±0.21^{a}	87.81±0.16^{bc}	90.51±0.16^{c}
Quinoa flour (3%)	88.42±1.09^{a}	87.60±0.16^{b}	90.71±0.21^{c}
Amaranth Flour (3%)	88.34±0.95^{a}	83.87±0.54^{a}	90.60±0.18^{c}
Quinoa starch (10%)	88.84±0.16^{b}	88.49±0.32^{cd}	91.72±0.10^{d}
Amaranth starch (10%)	88.57±0.21^{ab}	88.26±0.52^{c}	87.82±0.89^{a}
Corn starch (10%)	88.97±0.69^{b}	87.39±0.57^{b}	90.62±0.08^{c}
Quinoa flour (10%)	87.92±0.63^{a}	88.02±0.21^{c}	91.56±0.14^{d}
Amaranth flour (10%)	88.65±0.48^{b}	88.99±0.12^{d}	91.78±0.17^{d}
Vitamin C	91.17±0.05^{c}	91.17±0.05^{e}	89.39±0.00^{b}

In comparison to corn starch (reference), quinoa starch would be the best alternative at a 3% inclusion level since it had a higher value, indicating a higher antioxidant capacity, which is beneficial to human health and the preservation of food products. Amaranth starch and quinoa flour could also be used as alternatives since their values were not significantly different from those of corn starch in this study. Amaranth flour, which was lower and significantly different, might not be the best to use as an alternative to corn starch in fermented sausages.

At a 10% inclusion level, the DPPH scavenging activity value for amaranth flour was significantly ($p<0,05$) higher than for all other samples, with corn starch being the lowest. Corn starch was significantly ($p<0, 05$) lower and different from both quinoa starch and amaranth starch, and among the starches, quinoa starch had the highest. Corn starch showed reduced antioxidant performance in fermented sausages at a 10% inclusion level. Quinoa starch, amaranth starch, quinoa flour, and amaranth flour at a 10% inclusion level may be used as an alternative to corn starch (reference) since they exhibit benefits at higher inclusion levels.

Emulsion sausages made with quinoa starch, amaranth starch, quinoa flour, amaranth flour, and corn starch were significantly different ($p<0,05$) in the DPPH scavenging activity values. At the 3% inclusion level, amaranth starch had the highest value and was significantly different($p<0,05$) from all other samples, followed by quinoa flour and amaranth flour, and all had values higher than corn starch except for quinoa starch. However, corn starch and quinoa starch had no significant difference; therefore, all the samples could be used at 3% as an alternative to corn starch considering the benefits of DPPH scavenging to improve antioxidant capacity. At the 10% inclusion level for emulsion sausages, the DPPH scavenging activity was in the following order: AMF>QS>QF>CS>AMS. Amaranth starch had the lowest value and was significantly different($p<0,05$) from all other samples. Corn starch was also significantly different from all samples. Furthermore, quinoa starch, quinoa flour, and amaranth flour were significantly the same, considering the DPPH scavenging values at 10% inclusion levels in emulsion sausages. Quinoa starch, quinoa flour, and amaranth flour would be recommended for use as alternatives to corn starch because their antioxidant capacity, as indicated by DPPH scavenging activity, will be higher than that of the standard corn starch used in this study.

In general use of the samples (QS, AMS, CS, QF, AMF), the three types of sausages showed DPPH scavenging activity values above 70%, which reflects good antioxidant capacity. This property could highlight the contribution of the samples to oxidative stability in the sausages (Gulcin &

Alwasel, 2023). Emulsion sausages had higher DPPH scavenging activity, followed by fresh sausages and, lastly, fermented sausages. Fermentation conditions and starter culture appear to have negatively influenced the antioxidant potential of the flours and starches (Verni et al., 2019). While higher inclusion levels increased antioxidant activity in fresh and emulsion sausages, the reduced activity in fermented sausages may be due to fermentation processes altering the bioavailability of antioxidants. Li et al. (2018) reported a decrease in total phenols and flavonoid content due to fermentation. Quinoa starch and amaranth starch showed higher DDPH scavenging activity compared to corn starch, particularly at a 3% inclusion level for fresh and fermented sausages. Quinoa and amaranth starches produced comparable results on DDPH scavenging activity. Therefore, they can both be used as alternatives to corn starch in fresh, fermented, and emulsion sausages. According to Verni et al. (2019), a higher DDPH scavenging activity increases the shelf life of the sausages and promotes consumer health.

4 Conclusion

This study demonstrates that quinoa and amaranth starches and flours are effective alternatives to corn starch in sausage formulations, with performance varying by sausage type and inclusion level. Quinoa starch proved most effective in reducing cooking loss in fresh sausages and was optimal at 3% inclusion in fermented sausages, while amaranth starch performed better in emulsion sausages at both 3% and 10% inclusion levels. Water-holding capacity was notably higher in fresh sausages containing quinoa and amaranth starches. The pH values indicated amaranth starch as the best substitute in raw fresh sausages and quinoa in cooked fresh sausages. In fermented sausages, quinoa starch was superior in raw formulations, while both starches outperformed corn starch in cooked variants. Emulsion stability was enhanced by quinoa starch at 3% and amaranth starch at 10% inclusion, further supporting their suitability as substitutes for corn starch. Additionally, quinoa and amaranth provided higher antioxidant activity (DPPH scavenging) than corn starch, with stronger effects at 10% inclusion level, particularly in fresh and emulsion sausages. The findings suggest that incorporating quinoa and amaranth into sausage formulations can improve functional properties and antioxidant activity, offering valuable benefits for the food industry.

Acknowledgements

The authors would like to thank Midlands State University and the University of Namibia for providing access to laboratories and technical support for this project.

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