

# Quality Evaluation of Low-Fat Pork Sausages Using Quinoa Flour and Gum Arabic from *Acacia senegal* var. *kerensis*

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## Abstract

Pork sausages contain significantly high amounts of saturated fat and they have been linked to various cardiovascular diseases. Fat substitutes used to reduce the amount of saturated fat include starch, gums, soy, plant oils, cereal-based substitutes like chia and oats. Due to modification, such sausages have been reported to have undesirable sensory and physicochemical properties, such as hardening and lowered emulsion stability. Quinoa is a nutritious pseudo cereal comprising all the essential amino acids and has been shown to have good binding abilities. However, its potential has not yet been fully utilized in product development, especially in the meat industry. This research study aimed to investigate the effect of quinoa flour and gum Arabic on the physicochemical, nutritional, and textural properties of pork sausages. Quinoa flour was used in sausage formulation to partially substitute pork fat, while gum Arabic from *Acacia senegal* var. *kerensis* was used to stabilize the emulsion. The resulting sausages were analyzed for crude protein, crude fat, moisture, expressible moisture, pH, in vitro protein digestibility, and texture. The results indicated that, increase in the levels of quinoa flour significantly ( $p < 0.05$ ) increased the crude protein content from 11.83% to 17.94% and reduced the amount of crude fat from 29.73% to 10.41%. However, addition of quinoa led to a significant increase in hardness, gumminess and chewiness. On the other hand, increasing the levels of gum Arabic led to a significant ( $p < 0.05$ ) decrease in cooking loss, expressible moisture and hardness but it increased ash content. Combining quinoa flour and gum Arabic in low fat pork sausages improved their crude protein, crude fat, ash content, hardness and gumminess properties. The results of this study showed that quinoa flour and gum Arabic can be utilized to produce nutritious and acceptable low-fat pork sausages.

## Keywords

Pork Sausages, Quinoa Flour, Gum Arabic, Physicochemical Properties, Textural Properties

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## 1. Introduction

Consumers around the globe are increasingly becoming concerned about their well-being, and for this reason, the demand for nutritious and quality foods is on the rise [1] [2]. World Health Organization (WHO) limits the consumption of saturated fats to 10% and encourages replacing them with plant sources. However, pork sausages are a delicacy consumed by many people [3]. Furthermore, the consumption of pork is projected to increase to 127 Mt by 2030 accounting for 33% of the total meat increase consumption [4]. Pork fat is one of the main ingredients in formulating sausages and it accounts for approximately 30% of the total components [3] [5]. The large amount of pork fat in the sausages is a source of saturated fatty acids and cholesterol and has been linked to coronary heart disease, cancer, obesity, hypertension and other cardiovascular diseases [6]-[9]. Therefore, there is a need for total or partial replacement of pork fat with plant sourced substitutes such as quinoa flour to develop healthy low-fat sausages.

Quinoa presents an avenue for improving the nutritional quality of pork sausages [10] [11]. Quinoa could be a good pork fat substitute owing to its low fat content (2% - 9.5%) where 70% - 89.4% constitute unsaturated fatty acids that are made stable by vitamin E existing naturally in quinoa. Quinoa starch comprises smaller starch granules than other cereal grains, is freeze-thaw stable, and has minimum gelation temperature. For this reason, it can be used to make desirable textures such as smooth and creamy that resemble fats [12]. Furthermore, quinoa is made up of all essential amino acids, rich in dietary fiber and other nutrients [13]. Its dietary fiber is advantageous especially to celiac disease patients because it is gluten-free. Additionally, quinoa has been shown to lower the occurrence of free fatty acids; thus, it has the potential to be an antioxidant [12].

Quinoa could be a sustainable crop to fight malnutrition and lead to food security in African countries where its full potential is yet to be exploited [14]. This is based on the fact that quinoa is a climatic smart crop since it can grow even in harsh climatic conditions such as salt and drought-prone areas like some parts of African countries [15]. It could be an ideal crop to replace crops such as maize that are declining in production due to climate change [16]. One way of utilizing quinoa is by replacing fat in pork sausages. Studies such as one done by Pellegrini [17], show that quinoa could be a potential fat replacer in meat products such as sausages. Quinoa flour has no significant influence on the flavor of pork sausages [18]. The quinoa flavor is equally acceptable as that of pork sausages without quinoa flour.

There are various factors that influence the quality of pork sausages including

meat quality, processing technique, ingredients used and meat to fat ratio. Fat is one of the significant ingredients in sausage production. Typically, approximately 30% of fat is used in sausage formulation to stabilize meat emulsions [5]. It is also essential because it enhances sausage's juiciness, flavor, texture, and physicochemical properties such as water holding capacity [19] [20]. Substituting pork fat with non-meat substances such as quinoa, whey and soy proteins, gums, starch, oats, chia and canola presents a viable way of reducing saturated fats in pork sausages [21]. However, due to modification, some of the resulting sausages have been reported to have undesirable sensory and physicochemical properties, such as hardening and lowered emulsion stability [22]-[24]. For this reason, the use of emulsion stabilizers such as gum Arabic could be of significant help.

Gum Arabic from *Acacia senegal* var. *kerensis* has unique properties that make it suitable for its application in the meat industry. It can dissolve in either cold or hot water for up to 50%, unlike other vegetable gums [25]. It has a weak viscosity making it suitable for use in high concentrations without altering a product's viscosity. Gum Arabic is not reactive to chemical compounds and is tasteless and colorless; thus, it cannot alter a product's sensory properties, such as flavor. It is slightly acidic, with a pH range of 4.5 to 5.5. Moreover, gum arabic has both hydrophilic and hydrophobic ends, making it a good emulsifying agent for oil and water emulsions [26]. Arabinogalactan protein in the gum gives it its emulsifying and stabilizing effects. Research has shown that Gum Arabic from *senegal* var. *kerensis* used at 2.5% in making beef hams exhibited good binding ability, improved water holding capacity of beef hams, and maintained the sensory properties of the beef hams, such as beef flavor [27].

Therefore, this study developed novel pork sausages with low-fat content that were expected to be nutritious and palatable. They were made by partially substituting pork fat with quinoa flour at different levels (0% - 80%) and the emulsion was made stable to acquire the desired texture and juiciness using gum Arabic from *Acacia senegal* var. *kerensis*. The study explored their independent and interactive effects on both physicochemical and textural properties.

## 2. Materials and Methods

### 2.1. Materials

Quinoa seeds were sourced from Healthy U, Westside Mall in Nakuru, and lean pork meat and pork back fat from Njoro. Gum Arabic from *Acacia senegal* var. *kerensis* was procured from Kenya Forestry Research Institute Laboratories (KEFRI), Kenya.

### 2.2. Preparation of Sausages

Three groups of pork sausages were prepared. The control sample was formulated as shown in **Table 1**. The first group comprised sausage samples where pork fat (30%) was partially substituted with quinoa flour at levels of 0%, 20%, 40%, 60%

and 80% to determine the effect of quinoa flour. The second group was of samples prepared as a control with incorporation of gum Arabic from *Acacia senegal* var. *kerensis* (0%, 1%, 2%, 3% and 4%) to determine the effect of gum Arabic. Finally, samples in the last group were prepared by combining different quinoa flour levels with each level of gum Arabic to find out the effect of the interaction of quinoa flour and gum Arabic.

Samples were prepared with adjustments to the quinoa flour level and gum Arabic level where necessary. Chilled lean pork (65%) at a temperature of 0°C was minced using a mincer whose grinder disc ranged approximately between 2 mm and 3 mm. Common salt 1.5% and 0.1% Sodium tripolyphosphate were added, and comminution was done until a temperature of 2°C - 4°C was reached. Chilled water was incorporated, and continuous comminution was done until a sticky texture of the lean batter was attained and a temperature of 5°C reached. Chilled fat, spices and other non-meat ingredients were added, and comminution was continued to a temperature of 10°C. At the last stage, comminution was slowed to eliminate air bubbles. The resulting batter was then filled into artificial collagen casings, linked, twisted, vacuum packed and stored at a temperature of -18°C for analysis.

**Table 1.** Formulation of control pork sausages.

Ingredient	Control (0, 0)
Lean pork	65%
Pork fat	30%
Salt	1.5%
Sodium tripolyphosphate	0.1%
Sodium nitrite	0.016%
Ascorbic	0.044%
Monosodium glutamate	0.1%
Nutmeg	0.04%
Pepper	0.05%
Clove	0.05%
Ginger	0.05%
Ice	3%
Total	100%

## 2.3. Determination of Physicochemical Properties

### 2.3.1. Determination of Moisture Content

Determination of moisture content was done according to method 930.15 [28]. For each pork sausage, approximately 2.5 g sample was weighed into aluminium dishes after grinding and dried in an oven set at a temperature of 105°C to a constant weight that was attained after 3 hours. The aluminium dishes containing the samples were then cooled in a desiccator for about 10 minutes then weighed. The

analysis was done in triplicate. Percentage moisture content was then calculated as follows.

$$\text{Moisture content} = \frac{A - B}{C} \times 100\%$$

Where *A* was the weight of the crucible and wet sample, *B* was the weight of the crucible and dry sample and *C* is the weight of the sample.

### 2.3.2. Determination of Ash

The content of ash was determined according to method 930.05 [28]. Approximately 5g of pork sausage sample was weighed into a porcelain crucible previously calcined. A hot plate was then used to heat the sample to get rid of organic matter that produced smoke that was not required in the muffle furnace used. The sample was then placed in a muffle furnace and heated to 550°C for 12 hours. The samples were then left to cool to room temperature and weighed. Percentage ash content was then calculated using the formula below.

$$\text{Ash (\%)} = \frac{\text{weight of crucible + ash (g)} - \text{weight of crucible (g)}}{\text{weight of sample (g)}}$$

### 2.3.3. Determination of Crude Protein

The amount of protein was determined as described in 978.04 [28]. The Kjeldahl method was used to determine nitrogen content. Approximately 1g of sample was weighed into a Kjeldahl digestion flask then 10 ml of concentrated sulphuric acid and one Kjeldahl tablet catalyst were added to enable digestion. Forty percent sodium hydroxide was then used in neutralization and as a result ammonia gas was released. The gas was then distilled for 4 minutes and trapped in 50 ml of 0.1 N boric acid. The distillate collected was titrated with 0.1 N hydrochloric acid until the methyl red indicator (2 - 3 drops) turned pink, indicating the endpoint. Nitrogen content was then calculated using the following formula and later crude protein was calculated by multiplying the Nitrogen content with a conversion factor of 6.25.

$$N = 0.1 \times \frac{\text{corrected titre volume}}{\text{sample weight}} \times \frac{14\text{gN}}{1000} \times 100\%$$

$$\text{Protein} = \%N \times 6.25\%$$

Where corrected titre volume = (volume of acid sample – volume of acid blank), 0.1 = Normality of HCl, 14 g = atomic weight of nitrogen, 1000 = Mol, 6.25 = conversion factor.

### 2.3.4. Determination of Crude Fat

Fat determination was done using the Soxhlet method using petroleum ether as outlined in method 930.09 [28]. Approximately 5 g of mashed sample was weighed into an aluminum crucible and dried (moisture content above 8% caused hygroscopic petroleum ether to be saturated with water and its efficiency of lipid extraction is reduced) at 102°C for 5 hours (lower temperature to prevent binding of lipids to proteins and carbohydrates which forms complexes that make extraction

of the lipids difficult) then cooled in the desiccator. The sample was transferred to a thimble and a thin layer of cotton wool was used to wipe any remaining fat content in the aluminium crucible and was placed at the top of the thimble. The thimble was then placed in the soxhlet extraction. A clean, previously dried round bottom extraction flask was weighed and partially filled with 150 ml petroleum ether and placed in the extraction system. The heat from the heating mantle was adjusted such that the solvent dripped from the condenser to the sample at a rate of 6 drops per second. Extraction was done for 6 hours, the flask containing the extracted fat dried in a hot air oven at 105°C for 30 minutes and then cooled in a desiccator. The contents were later weighed, and crude fat percentage was calculated as shown below.

$$\text{Crude fat} = \frac{(\text{weight of flask + oil after extraction}) - (\text{weight of flask})}{\text{sample weight}} \times 100\%$$

### 2.3.5. Expressible Moisture

To determine expressible moisture, approximately 10 g sample of the pork sausages was centrifuged (Model: LCB-0153B-A2, Watts: 1.2 kW/6 A, Serial No: PXOQXR0402O from DAIHAN LABTECH CO., LTD.) at 860 xg at -20°C for about 8 minutes. The expressible moisture was then expressed as a percentage by dividing the difference in sample weight before and after centrifugation by the original sample weight and multiplying by 100.

$$\text{Expressible moisture \%} = \frac{\text{original weight of sample} - \text{weight of sample after centrifugation}}{\text{original sample weight}} \times 100\%$$

### 2.3.6. Cooking Loss

Samples of cooked and uncooked sausages were weighed separately. The cooking loss percentage was then determined by finding the difference between the sample's original weight and the sample's weight after cooking, then dividing by the original weight and multiplying by 100.

$$\text{Cooking loss \%} = \frac{\text{original uncooked sample weight} - \text{weight of cooked sample}}{\text{original uncooked sample weight}} \times 100\%$$

### 2.3.7. PH Determination

A digital pH meter was used to determine pH values. Standard buffer solutions at pH 4.0 and pH 7.0 were used to calibrate the pH meter. Ten grams sample sausages were cut into pieces, 90 ml distilled water added, homogenization done to obtain a slurry and the pH recorded.

### 2.3.8. In Vitro Protein Digestibility

To determine the protein digestibility of the resulting sausages, the nitrogen content of undigested sausage sample was measured using Kjeldahl method then a two-step in vitro digestion to mimic digestion in the stomach and small intestines was carried out using the procedures highlighted from previous studies [29]-[31]. Samples of 1 g were weighed into 50 ml centrifuge tubes and 15 ml of 0.1 N HCl

was added to aid activation of the enzyme. The pH was measured and adjusted using an NAOH to about 2.5. Then, 0.02 g of pepsin (CAS: 9001-75-6) of 0.8 Anson unit/mg was added and incubated in a water bath at 37°C for 2.5 hours while shaking the tubes using a Lab Rotator at intervals of 10 - 15 min as the digestion went on. The pH was then adjusted to 8.0 with 1.0 N NaOH then 0.02 g trypsin (CAS: 9002-07-7, India) and 0.02 g of chymosin (CAS: 9001-98-3) was added into the tubes and incubated for 3.5 hours at 37°C, shaking the tubes at intervals of 10 - 15 min until the digestion was complete. The mixture was centrifuged at 3500 xg for 20 min to enable extraction of the supernatant. The supernatant was dried at 102°C in the oven to a constant dry weight and then 0.2 g was weighed and analyzed for crude protein using the Kjeldahl method. The nitrogen content of digested sausage sample was measured, and protein digestibility was obtained as follows.

$$PD\% = B/A \times 100\%$$

Where, PD is protein digestibility; *B* is the total nitrogen before digestion and *A* is the total nitrogen after digestion.

### 2.3.9. Texture Profile Analysis

Each sausage was cut to a thickness of 2 cm. The sausages were compressed to 30% their original height. A texture analyzer from Stable Micro Systems (TA. XT. plus Texture Analyser) was used to evaluate the texture profile of the sausages. The texture analyzer had a force capacity of 50 kg meaning it could measure up to 50 kg in force, it had a force resolution of 0.1 g, pre-test speed of 1 mm/sec, a test speed of 5 mm/sec, post-test speed of 5 mm/sec, time was 5 sec, and the trigger force was set to 5 g. An aluminum cylinder probe with a diameter of 35 mm was used. This was done at room temperature. Hardness, cohesiveness, springiness, resilience, gumminess and chewiness textural parameters were analyzed.

### 2.4. Statistical Analysis

The main effect of the study was the level of quinoa at 0% ,20%, 40%, 60%, and 80% and the level of gum Arabic at 0%, 1%, 2%, 3%, and 4%. This made for a 5 × 5 factorial experiment in a completely randomized design. SAS statistical analysis system version 9.4 (2013) software was used to analyze the data for variance analysis (ANOVA). A confidence level of 95% was applied. Data was reported as means ± standard error. Tukey's test was used to determine differences between the mean values for the different treatments ( $p < 0.05$ ).

## 3. Results and Discussion

### 3.1. Physicochemical Properties of Pork Sausages with Quinoa and Gum Arabic

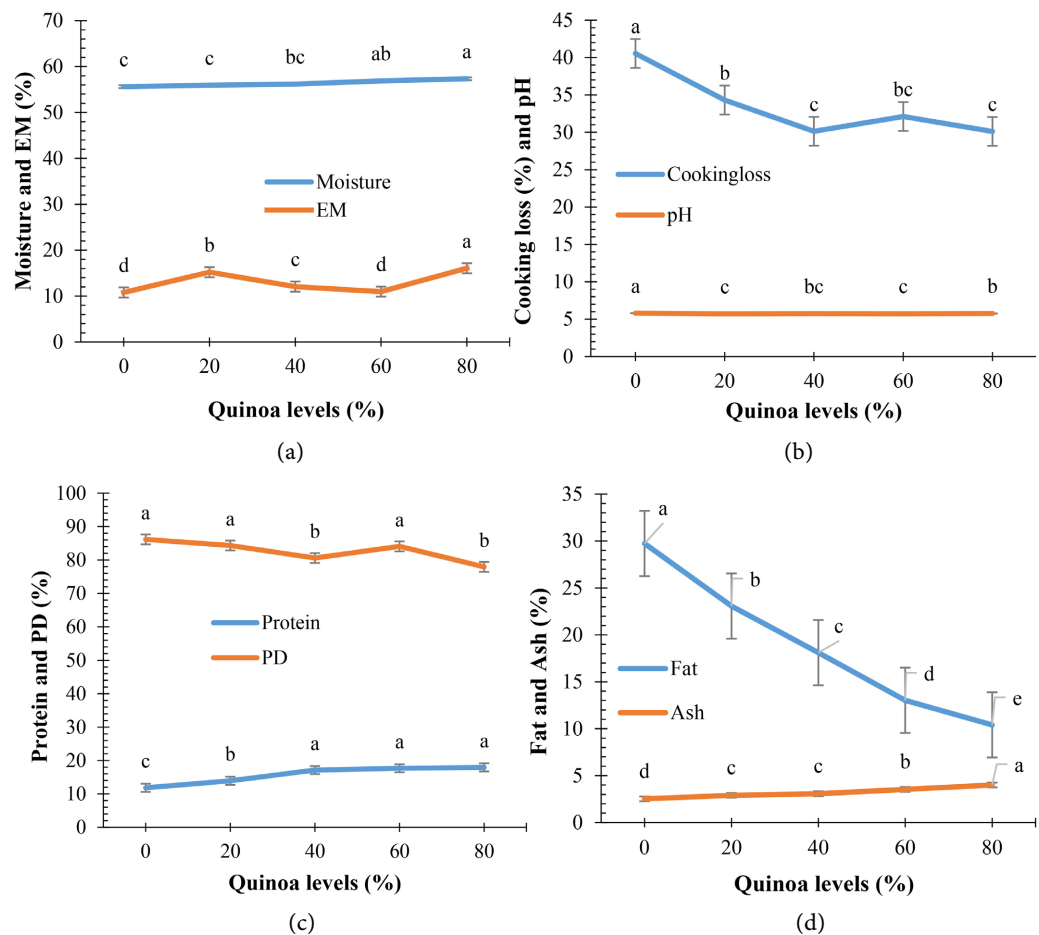
Physicochemical properties of pork sausages substituted with different levels of quinoa are shown in **Figure 1**. Moisture content (MC) increased with an increase in the levels of quinoa substitution in the pork sausages although there was no

significant difference ( $p < 0.05$ ) between the control and the sample at 20% quinoa substitution. The significant increase in MC could be due to high dietary fiber and protein in quinoa flour, which led to more water being entrapped in the meat matrix [10]. The control sample and the sample with 60% quinoa substitution had the lowest expressible moisture (EM) while the rest had significantly higher values. The reason behind this observation could be the higher moisture content of the samples, which led to higher expressible moisture compared to the control. Additionally, quinoa flour like other cereal based non-meat ingredients has a lower water holding capacity as compared to fat [32]. Therefore, replacing fat with quinoa flour lowered the emulsion stability leading to high EM. Cooking loss reduced significantly ( $p < 0.05$ ) with increase in quinoa substitution although there was no significant difference between samples with 40% and 80% quinoa substitution and there was a slight increase in cooking loss for the sample with 60% quinoa substitution, but it was lower (32.11%) than the control (40.54%). Cooking loss was significantly reduced ( $p < 0.05$ ), as shown in **Figure 2(b)**, since quinoa flour has an amylose content of 3% - 20% which enhanced its water binding ability [33], thus preventing cooking loss.

The results of pH values are shown in **Figure 1(b)**. The pH of the control was significantly higher ( $p < 0.05$ ) than the rest of the samples. Nevertheless, they all had a range of 5.76 - 5.8 which is within the acceptable levels of pork sausages. The reduction in pH with increase in quinoa flour in the sausages may be attributed to some saponins that may have remained in the quinoa flour even after reducing them (through soaking for 24 hours) [34]. The fat content of all samples decreased with increase in quinoa amount because quinoa flour contains approximately 1.92% - 6% fat thus increasing its proportion resulted in significant fat reduction. Other researchers also reported an effective reduction in the amount of fat content in meat products where the fat was substituted with non-meat ingredients such as cereal flours among others [24] [35]-[38]. These reports showed that fat substitution with non-meat ingredients such as cereal flours among others is effective in reducing the amount of fat content in meat products.

Crude protein increased significantly ( $p < 0.05$ ) with increase in the amount of quinoa (**Figure 1(c)**). The protein content of the samples without quinoa was 11.83% whereas samples with quinoa flour had higher values of up to 16.67%. This is attributed to the fact that the protein content of quinoa is high (14.5%). Therefore, it was able to boost the protein content of the sausages as the substitution levels with pork fat increased since the fat does not contain protein. For this reason, it can be concluded that it is possible to enhance the nutritional value of reduced fat sausages formulated with quinoa flour. Similar data was reported by [10] [37], who detected an increase in the protein content of their meat products (beef meatball, meat patties and reduced fat sausages) with increased amounts of quinoa flour. Protein digestibility (PD) of the samples reduced with the addition of quinoa (**Figure 1(c)**). However, the reduction was not significant except for samples with 40% and 80% quinoa. This observation may be due to the interaction of proteins with non-protein substances during processes such as milling and

cooking [39]. The presence of starch and fiber in quinoa flour reduces protein digestibility. Dry weight of quinoa is made up of 50% of starch that interacts with proteins reducing its digestibility [40]. Starch being a carbohydrate is able to bind to water molecules thus it takes up gastric fluid that usually contains HCL and pepsin that is responsible for protein digestion (breaking down proteins into peptides). This hinders the entry of the acid and pepsin into the protein. Dietary fibre contains pectin and other gel-forming polysaccharides that form a gel-like substance in the digestive system that causes retention of amino acids and peptides thus reducing the accessibility of proteases to the proteins [41] [42]. Nevertheless, all the samples had a range of 77.94% - 86.17% protein digestibility that is in line with protein digestibility of pork sausages that ranges between 84.23% and 90.5% [43]. Quinoa protein isolates have a high protein digestibility ranging from 76.3% to 80.5% [44] [45]. The ash content increased significantly ( $p < 0.05$ ) with an increase in the amount of quinoa flour due to the high content of minerals in quinoa [13].

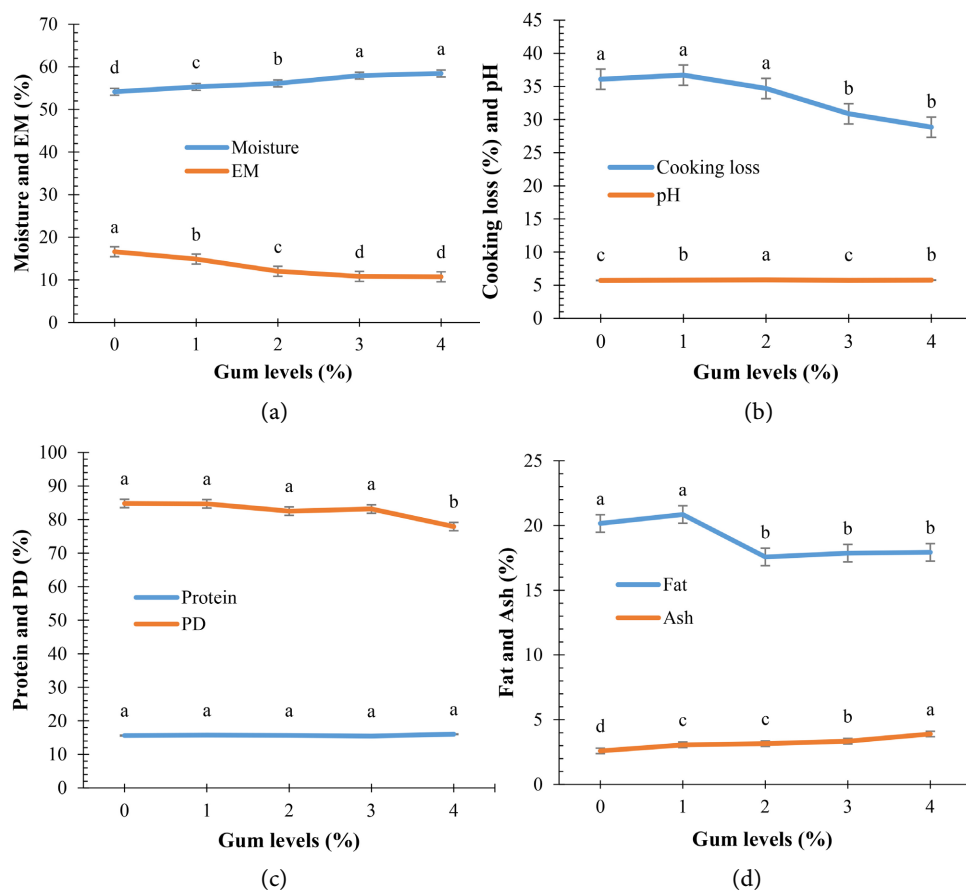


Means with similar letters are not significantly different ( $p < 0.05$ ).

**Figure 1.** Physicochemical properties of pork sausages substituted with different levels of quinoa.

Physicochemical properties of pork sausages substituted with different levels of

gum are shown in **Figure 2**. Increasing the levels of gum substitution in pork sausages resulted in significant ( $p < 0.05$ ) corresponding decrease in cooking loss. Similar results were obtained by [27] [46], where gum Arabic led to reduction of extractable moisture in cooked extended beef rounds and lowered cook loss in mushroom-substituted sausages respectively. This is attributed to the fact that gum Arabic is a hydrocolloid thus it has the ability to bind water and other components leading to a product less prone to syneresis during cooking. Research shows that when gum Arabic from *Acacia senegal* is heated, the proteinaceous components aggregate producing a hydrogel form with enhanced mechanical properties and water binding properties which may be the reason for lowering cooking loss [47]. There was no significant difference in crude protein among samples (**Figure 2(c)**). This observation is due to the low amount of protein (3.42%) in gum Arabic [48]; thus it did not significantly affect the overall crude protein of the samples. Protein digestibility was also not significantly different among samples except for the sample with 4% gum Arabic that showed a significantly lower ( $p < 0.05$ ) PD than the rest of the samples. Gum Arabic at 4% level might have interfered negatively with the protein digestion leading to a lower PD observed in the sample.



Means with similar letters are not significantly different ( $p < 0.05$ ).

**Figure 2.** Physicochemical properties of pork sausages substituted with different levels of gum Arabic.

There was a significant increase ( $p < 0.05$ ) in moisture content with increase in gum Arabic levels unlike expressible moisture that significantly decreased ( $p < 0.05$ ) with increase in gum Arabic levels. This is attributed to the fact that gum Arabic has the ability to improve water holding capacity of food products thus they are able to retain an appreciable amount of moisture [27] [47] [48].

**Figure 2(d)** showed that the ash content increased significantly ( $p < 0.05$ ) with increase in gum Arabic levels. The fact that gum Arabic has high amount of ash content of 3.6% [48] may be the reason for this observation.

The combined effect of substitution with Quinoa flour and gum Arabic on physicochemical properties of pork sausages is shown in **Table 2**.

**Table 2.** Effect of Quinoa and gum Arabic substitution levels on physicochemical properties of pork sausages.

Quinoa (%)	Gum (%)	Moisture (%)	Fat (%)	Protein (%)	PD (%)	EM (%)	Ash (%)	Cooking loss (%)	pH
	0	53.70 ± 0.74 <sup>h</sup>	32.14 ± 0.49 <sup>a</sup>	12.58 ± 0.32 <sup>de</sup>	88.21 ± 1.31 <sup>a</sup>	17.80 ± 0.35 <sup>b</sup>	1.30 ± 0.03 <sup>l</sup>	42.33 ± 2.07 <sup>ab</sup>	5.77 ± 0.02 <sup>bcd</sup>
	1	54.87 ± 0.47 <sup>fgh</sup>	32.13 ± 0.25 <sup>a</sup>	11.87 ± 0.41 <sup>de</sup>	88.24 ± 0.71 <sup>a</sup>	16.30 ± 0.22 <sup>cd</sup>	1.97 ± 0.06 <sup>k</sup>	43.77 ± 0.62 <sup>a</sup>	5.78 ± 0.02 <sup>bcd</sup>
0	2	55.10 ± 0.60 <sup>efgh</sup>	29.65 ± 0.19 <sup>ab</sup>	11.98 ± 0.37 <sup>de</sup>	88.28 ± 0.35 <sup>a</sup>	9.71 ± 0.17 <sup>m</sup>	2.63 ± 0.10 <sup>ij</sup>	43.24 ± 1.29 <sup>a</sup>	5.89 ± 0.02 <sup>a</sup>
	3	57.09 ± 0.29 <sup>bcd</sup>	28.23 ± 0.58 <sup>abc</sup>	11.32 ± 0.22 <sup>e</sup>	87.58 ± 0.61 <sup>ab</sup>	5.22 ± 0.42 <sup>o</sup>	2.86 ± 0.11 <sup>hij</sup>	38.65 ± 1.73 <sup>abc</sup>	5.75 ± 0.01 <sup>bcd</sup>
	4	57.33 ± 0.30 <sup>abcd</sup>	26.49 ± 1.00 <sup>bcd</sup>	11.41 ± 0.22 <sup>e</sup>	78.53 ± 0.59 <sup>cde</sup>	4.92 ± 0.06 <sup>o</sup>	3.90 ± 0.08 <sup>bc</sup>	34.73 ± 0.78 <sup>bcd</sup>	5.81 ± 0.01 <sup>ab</sup>
	0	53.80 ± 0.60 <sup>gh</sup>	25.44 ± 2.80 <sup>bcd</sup>	13.69 ± 0.29 <sup>de</sup>	86.82 ± 1.39 <sup>abc</sup>	17.22 ± 0.17 <sup>bc</sup>	2.43 ± 0.05 <sup>jk</sup>	37.78 ± 0.84 <sup>abcd</sup>	5.67 ± 0.01 <sup>fgh</sup>
	1	55.00 ± 0.41 <sup>fgh</sup>	24.40 ± 0.74 <sup>cd</sup>	13.62 ± 1.49 <sup>de</sup>	86.44 ± 0.95 <sup>abc</sup>	14.63 ± 0.11 <sup>efg</sup>	2.88 ± 0.07 <sup>ghij</sup>	35.51 ± 1.21 <sup>abcde</sup>	5.75 ± 0.04 <sup>bcd</sup>
20	2	55.20 ± 0.46 <sup>efgh</sup>	20.82 ± 0.97 <sup>efgh</sup>	14.28 ± 0.25 <sup>cd</sup>	86.90 ± 2.15 <sup>abc</sup>	15.82 ± 0.17 <sup>de</sup>	2.92 ± 0.14 <sup>ghij</sup>	38.25 ± 2.47 <sup>abc</sup>	5.78 ± 0.01 <sup>bcd</sup>
	3	57.50 ± 0.26 <sup>abcd</sup>	22.19 ± 0.12 <sup>defg</sup>	13.62 ± 0.44 <sup>de</sup>	82.37 ± 1.34 <sup>abcd</sup>	15.14 ± 0.28 <sup>def</sup>	3.00 ± 0.07 <sup>fghij</sup>	29.32 ± 2.45 <sup>efgh</sup>	5.70 ± 0.00 <sup>cdefgh</sup>
	4	58.22 ± 0.14 <sup>abc</sup>	22.53 ± 0.73 <sup>defg</sup>	14.46 ± 0.22 <sup>bcd</sup>	79.18 ± 2.42 <sup>bcd</sup>	13.27 ± 0.18 <sup>ghij</sup>	3.27 ± 0.11 <sup>defgh</sup>	30.68 ± 2.95 <sup>cdefgh</sup>	5.69 ± 0.01 <sup>defgh</sup>
	0	53.93 ± 0.03 <sup>gh</sup>	18.62 ± 0.35 <sup>ghij</sup>	16.61 ± 0.73 <sup>abc</sup>	81.12 ± 1.74 <sup>abcde</sup>	14.64 ± 0.11 <sup>efg</sup>	2.68 ± 0.04 <sup>ij</sup>	35.88 ± 1.14 <sup>abcde</sup>	5.75 ± 0.02 <sup>bcd</sup>
	1	54.54 ± 0.48 <sup>fgh</sup>	19.94 ± 1.55 <sup>fghi</sup>	17.40 ± 0.38 <sup>a</sup>	79.83 ± 2.43 <sup>abcde</sup>	13.72 ± 0.30 <sup>ghi</sup>	3.17 ± 0.08 <sup>efghi</sup>	33.17 ± 1.28 <sup>cdefg</sup>	5.81 ± 0.01 <sup>ab</sup>
40	2	55.82 ± 0.29 <sup>defg</sup>	14.02 ± 0.83 <sup>ijklmn</sup>	16.95 ± 0.31 <sup>abc</sup>	80.90 ± 1.39 <sup>abcde</sup>	9.97 ± 0.36 <sup>m</sup>	2.94 ± 0.06 <sup>fghij</sup>	27.47 ± 0.66 <sup>efgh</sup>	5.80 ± 0.01 <sup>b</sup>
	3	57.99 ± 0.71 <sup>abc</sup>	17.35 ± 1.30 <sup>ghijk</sup>	17.75 ± 0.38 <sup>abc</sup>	82.39 ± 1.15 <sup>abcd</sup>	12.30 ± 0.11 <sup>jk</sup>	3.07 ± 0.07 <sup>fghi</sup>	28.96 ± 1.81 <sup>efgh</sup>	5.63 ± 0.02 <sup>h</sup>
	4	58.70 ± 0.12 <sup>ab</sup>	20.65 ± 0.57 <sup>efgh</sup>	17.03 ± 0.09 <sup>a</sup>	78.73 ± 2.18 <sup>cde</sup>	9.70 ± 0.26 <sup>m</sup>	3.51 ± 0.06 <sup>cdef</sup>	25.16 ± 1.07 <sup>gh</sup>	5.76 ± 0.01 <sup>bcd</sup>
	0	54.38 ± 0.23 <sup>fgh</sup>	15.27 ± 1.07 <sup>ijklm</sup>	16.85 ± 0.32 <sup>a</sup>	87.37 ± 1.36 <sup>ab</sup>	12.78 ± 0.22 <sup>ijk</sup>	2.90 ± 0.09 <sup>ghij</sup>	32.69 ± 1.76 <sup>cdefg</sup>	5.65 ± 0.03 <sup>gh</sup>
	1	55.78 ± 0.21 <sup>defgh</sup>	15.66 ± 1.54 <sup>hijk</sup>	18.17 ± 0.37 <sup>a</sup>	87.53 ± 0.51 <sup>ab</sup>	11.81 ± 0.40 <sup>kl</sup>	3.44 ± 0.14 <sup>cdefg</sup>	37.82 ± 0.87 <sup>abcd</sup>	5.75 ± 0.02 <sup>bcd</sup>
60	2	57.09 ± 0.48 <sup>bcd</sup>	12.92 ± 0.48 <sup>klmn</sup>	17.66 ± 0.40 <sup>a</sup>	82.83 ± 1.10 <sup>abcd</sup>	10.65 ± 0.07 <sup>lm</sup>	3.41 ± 0.17 <sup>cdefgh</sup>	34.02 ± 1.23 <sup>bcd</sup>	5.80 ± 0.01 <sup>b</sup>
	3	58.25 ± 0.52 <sup>abc</sup>	10.37 ± 1.15 <sup>mn</sup>	17.52 ± 0.60 <sup>a</sup>	87.27 ± 0.90 <sup>ab</sup>	7.27 ± 0.09 <sup>n</sup>	3.79 ± 0.10 <sup>bcd</sup>	26.26 ± 1.18 <sup>fgh</sup>	5.76 ± 0.01 <sup>bcd</sup>
	4	58.85 ± 0.22 <sup>ab</sup>	10.92 ± 1.08 <sup>lmn</sup>	18.13 ± 0.06 <sup>a</sup>	75.41 ± 2.09 <sup>de</sup>	12.33 ± 0.25 <sup>jk</sup>	4.15 ± 0.11 <sup>ab</sup>	29.78 ± 1.73 <sup>defgh</sup>	5.70 ± 0.00 <sup>cdefgh</sup>
	0	54.95 ± 0.16 <sup>fgh</sup>	9.36 ± 1.12 <sup>n</sup>	18.32 ± 0.48 <sup>a</sup>	80.57 ± 2.10 <sup>abcde</sup>	20.71 ± 0.12 <sup>a</sup>	3.67 ± 0.05 <sup>bcd</sup>	31.73 ± 1.23 <sup>cdefgh</sup>	5.69 ± 0.01 <sup>efgh</sup>
80	1	56.29 ± 0.15 <sup>cdef</sup>	12.10 ± 0.94 <sup>lmn</sup>	17.67 ± 1.04 <sup>a</sup>	81.49 ± 1.55 <sup>abcde</sup>	18.04 ± 0.12 <sup>b</sup>	3.86 ± 0.09 <sup>bc</sup>	33.27 ± 1.33 <sup>cdefgh</sup>	5.74 ± 0.01 <sup>bcd</sup>

## Continued

	2	57.38 ± 0.49 <sup>abcd</sup>	10.42 ± 0.56 <sup>mn</sup>	17.40 ± 0.38 <sup>a</sup>	73.69 ± 2.21 <sup>e</sup>	13.99 ± 0.07 <sup>fighi</sup>	3.85 ± 0.21 <sup>bc</sup>	30.45 ± 0.43 <sup>cdefgh</sup>	5.76 ± 0.00 <sup>bcdef</sup>
80	3	58.94 ± 0.09 <sup>ab</sup>	11.13 ± 0.99 <sup>lmn</sup>	17.18 ± 0.22 <sup>ab</sup>	76.19 ± 0.80 <sup>de</sup>	14.21 ± 0.16 <sup>figh</sup>	3.98 ± 0.12 <sup>bc</sup>	31.18 ± 0.81 <sup>cdefgh</sup>	5.79 ± 0.01 <sup>bc</sup>
	4	59.19 ± 0.27 <sup>a</sup>	9.06 ± 0.92 <sup>n</sup>	19.12 ± 0.59 <sup>a</sup>	77.76 ± 1.60 <sup>de</sup>	13.46 ± 0.31 <sup>ghij</sup>	4.65 ± 0.20 <sup>a</sup>	23.93 ± 3.90 <sup>h</sup>	5.83 ± 0.01 <sup>ab</sup>

Data is presented as mean ± standard error. Means along the column followed by different superscript letters are significantly different ( $p < 0.05$ ).

PD = Protein digestibility; EM = Expressible moisture.

The control sample (0, 0) had the lowest moisture content whereas the samples with 80% quinoa and 4% gum Arabic had the highest moisture content. This is attributed to the fact that both quinoa and gum Arabic have the ability to bind water. Quinoa flour contains dietary fibre and proteins with a considerable amount of glutamic and aspartic acid that enables absorption of water and formation of a gel that traps water in the sausage emulsion [10] [49]. On the other hand gum Arabic has a high water holding capacity thus preventing leaks of water from the sausage matrix [27]. In terms of crude fat, the control and the sample with 1% gum Arabic had the highest fat content while the samples with 80% quinoa, 4% and 0% gum Arabic had the lowest amount. The reason behind this observation is the low amount of fat (5% - 7%) in quinoa flour [50] thus increasing the amount led to a decrease in fat content being substituted. The sample with 80% quinoa and 4% gum Arabic had the highest crude protein while the sample with 0% quinoa and 3% gum Arabic had the lowest protein content. This is based on the high amount of crude protein in quinoa flour (14.5%) and the fact that pork fat does not contain any protein content. The sample with 0% quinoa and 2% gum Arabic had the highest protein digestibility while the sample with 80% quinoa and 2% gum Arabic had the lowest protein digestibility. Quinoa protein digestibility is quite high but it may be affected by hydrolase inhibitors and enzyme inhibitory effects of quinoa phenolic contents [51]. The sample containing 0% quinoa and 4% gum Arabic had the lowest expressible moisture while the sample with 80% quinoa and 0% gum Arabic had the highest. The reason behind this could be the emulsifying and stabilizing ability of gum Arabic due to arabinogalactan-protein thus even external forces applied are not able to destabilize the emulsion leading to less expressible moisture in samples that have high amounts of gum Arabic [52]. On the other hand, quinoa flour has the ability to absorb water but retaining it effectively under stress is not possible because the matrix is destabilized leading to higher amounts of expressible moisture [53]. Combining gums with protein sources has been proved to be effective in emulsion stability [54]. The sample with 80% quinoa and 4% gum Arabic had the highest ash content while the control had the lowest amount. This is because both quinoa flour and gum Arabic are rich in minerals [13] [48]. The sample with 0% quinoa and 1% gum Arabic had the highest cooking loss while the sample with 80% quinoa and 4% gum Arabic had the lowest cooking loss. The addition of more than 2.5% gum Arabic is effective in reducing cooking loss therefore, concentrations less than that

might be ineffective [27]. Quinoa flour absorbs water whereas gum Arabic that is heat stable stabilizes the sausage emulsion even under heat treatment [47]. The sample with 0% quinoa and 2% gum Arabic had the highest pH while the sample with 40% quinoa and 3% gum Arabic had the lowest. Addition of both quinoa and gum Arabic could have altered the pH of the samples.

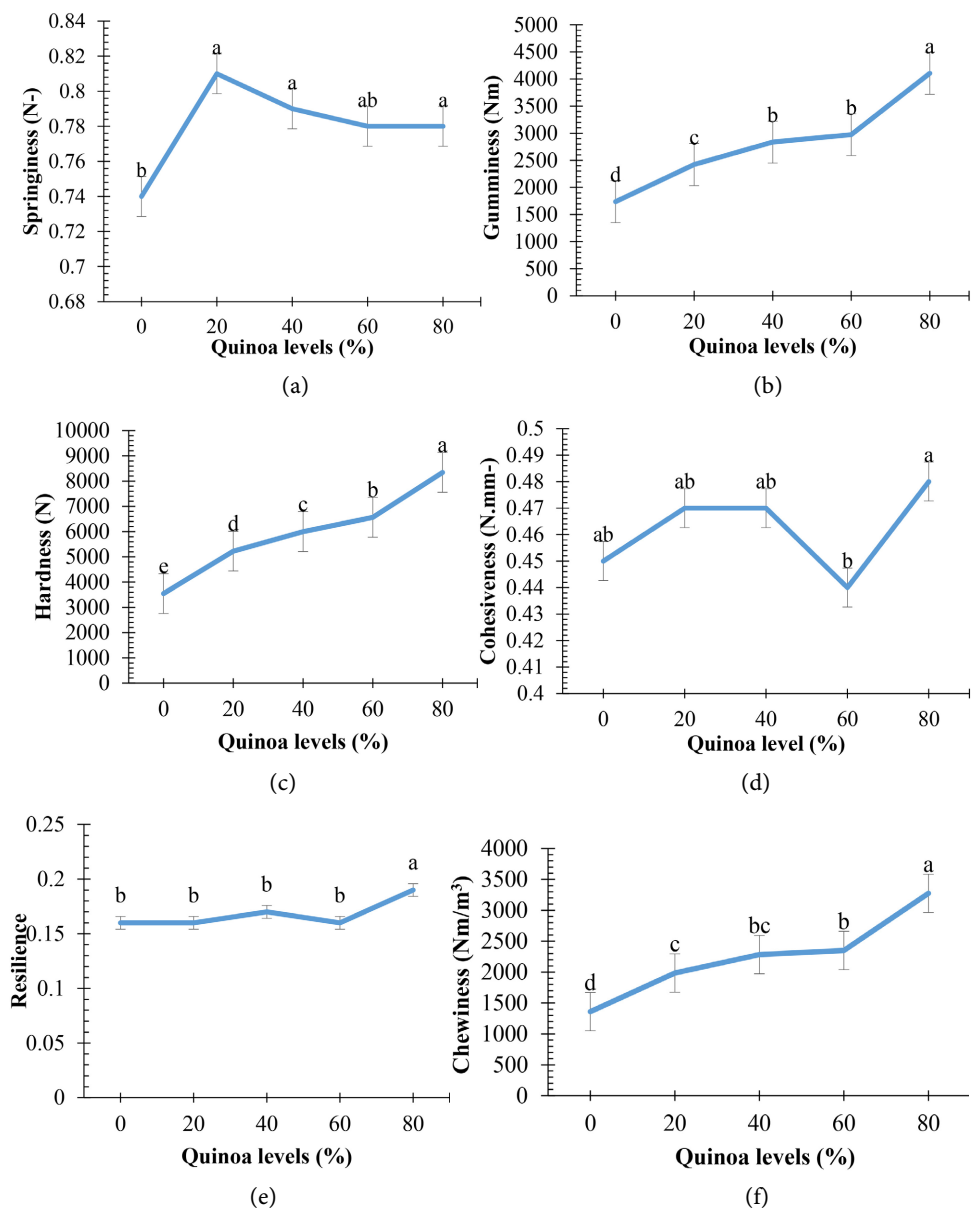
### 3.2. Textural Properties of Pork Sausages with Quinoa and Gum Arabic

The effect of quinoa substitution on textural properties of pork sausages is shown in **Figure 3**. The results showed that hardness of the sausages increased significantly ( $p < 0.05$ ) with increase in quinoa levels. This is attributed to reduction of fat with increase in quinoa levels. The higher the fat reduction in sausages the higher the hardness [55]. Fat is responsible for the desired texture in sausages [19] [20]. Replacing it with quinoa flour led to sausage hardness. The reason behind this could be the low-fat content in quinoa flour and the fact that it is mainly made up of unsaturated fatty acids unlike pork fat that is made up of saturated fatty acids. Saturated fatty acids are usually preferred in sausage making because they have a high melting point thus provide good emulsion stability during storage even at room temperature. On the contrary, plant oils are made up of unsaturated fatty acids hence have a low melting point. This leads to poor emulsion stability since the fat melts and dissociates from the sausages after cooking giving them a hard texture [56].

Furthermore, quinoa constitutes starch and dietary fiber that could have contributed to increased hardness in the sausages. Different studies have found that incorporating dietary fibre into meat products leads to increased hardness [57]-[59]. Starch which is mainly made up of amylose and amylopectin undergoes gelatinization and retrogradation leading to changes in texture of food matrices during and after processing [60]. Increased hardness could also be attributed to improved firmness and gel strength due to the presence of starch in the sausage emulsion [61]. Cohesiveness increased in all the samples except in the sample containing 60% quinoa flour. Notably there was no significant difference ( $p < 0.05$ ) between the control and samples with 20% and 40% quinoa. Cohesive products have the ability to stick together even under stress including compression. This could be attributed to high fiber in quinoa and high protein with good bonding in between and with other proteins in the sausage matrix [32] [62]. Springiness was high in all the samples when compared to the control. The reason for this could be the high amount of protein in all the samples as compared to the control. Denatured proteins interact with each other and fat, forming a gel-like matrix that provides structure and elasticity to the sausage, enhancing its ability to resist compression and bounce back, adding to springiness [62]. Gumminess and chewiness increased significantly ( $p < 0.05$ ) with increase in quinoa levels. These two texture attributes are derived, and their behavior is influenced by the primary parameters they are dependent on. [40] found that adding quinoa seeds to meatballs signi-

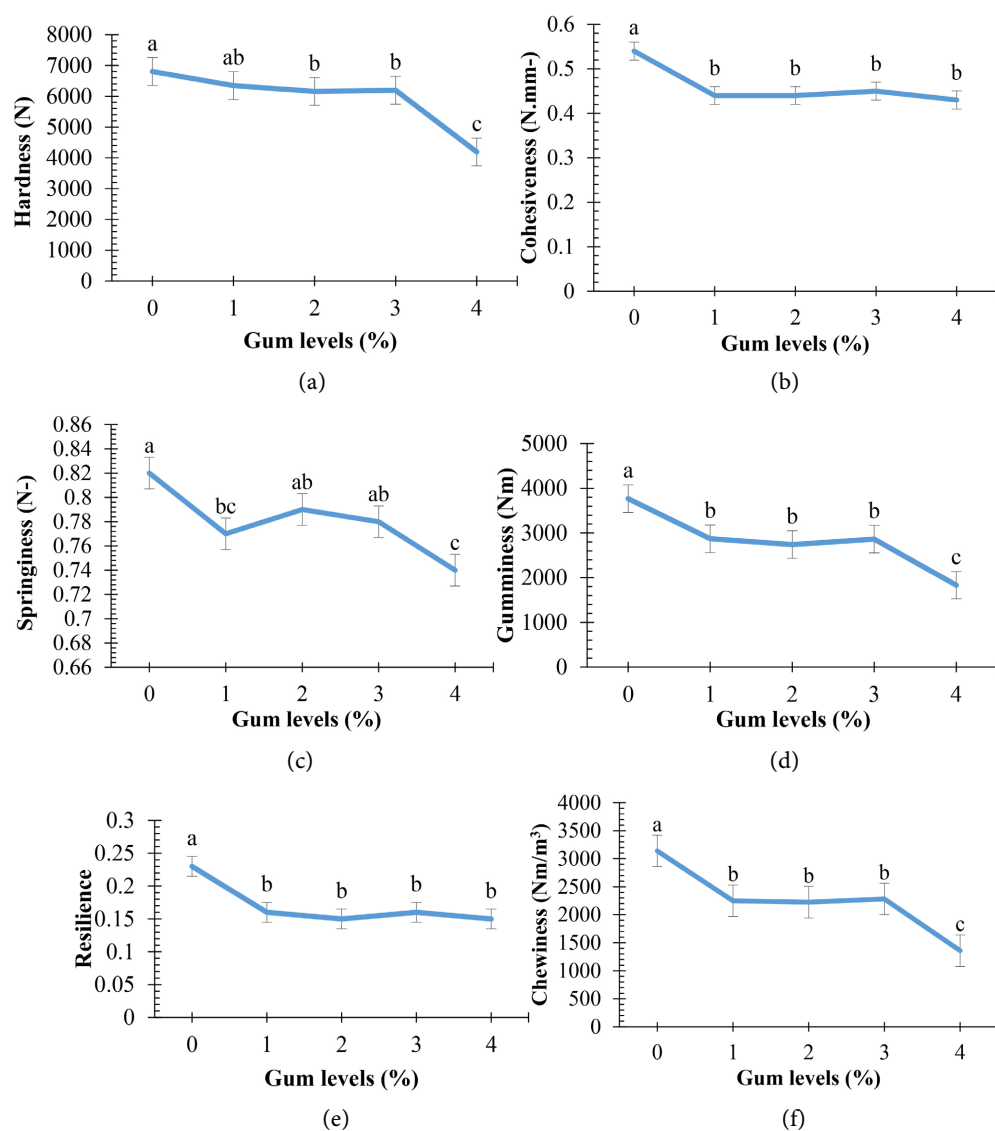
ificantly increased ( $p < 0.05$ ) the chewiness. Quinoa flour contains globulins and albumins that can form bonds with pork proteins particularly myosin resulting in a resilient protein network that enhances the chewiness and gumminess of the sausages [63]. Therefore, more force was required to break down the matrix than that in the control sample that had less protein content.

The effect of gum Arabic on textural properties of pork sausages is shown in **Figure 4**. Hardness significantly reduced ( $p < 0.05$ ) with increase in gum Arabic levels. This is attributed to the ability of gum Arabic to stabilize and emulsify oil and water emulsions due to the presence of both hydrophilic and hydrophobic ends enhanced by arabinogalactan protein [22] [59].



Means with similar letters are not significantly different ( $p < 0.05$ ).

**Figure 3.** Effect of quinoa substitution on textural properties of pork sausages.



Means with similar letters are not significantly different ( $p < 0.05$ ).

**Figure 4.** Effect of gum Arabic on textural properties of pork sausages.

[64] reported that the hardness of emulsified sausages whose fat was replaced with 100% oleogels made of gum Arabic and other gums was found to be similar to that of the control group and as the substitution ratio of oleogels increased from 25% to 100%, the hardness of the emulsified sausages decreased. Another research study reported similar observation when gums (gum Arabic and guar gum) were added to chicken nuggets at different concentrations of 0.5%, 1% and 1.5%. It was found that the hardness of the chicken nuggets reduced significantly ( $p < 0.05$ ) irrespective of the type of gum and level of addition [65]. The control had the highest cohesiveness as compared to the other samples that were not significantly different from each other. Comparable results were observed by [65] where cohesiveness of chicken nuggets decreased with the addition of gum Arabic. Springiness decreased significantly ( $p < 0.05$ ) in all the samples as compared to the

control. Gumminess and chewiness decreased significantly ( $p < 0.05$ ) as compared to the control but there was no significant difference ( $p < 0.05$ ) among samples with 1%, 2% and 3% gum levels. This is attributed to the fact that gum Arabic has a low viscosity thus it did not significantly thicken or add gumminess to the sausages [26].

The effect of Quinoa and gum Arabic substitution levels on textural properties of pork sausages is shown in **Table 3**. The sample with the highest hardness was that with 80% quinoa level and 0% gum Arabic while sample with 0% quinoa and 4% gum Arabic had the least. Pork fat is a stabilizer in sausages that means substituting it with quinoa flour leads to hard sausages because quinoa has poor emulsion stability thus cannot retain juices. However, gum Arabic is a good emulsion stabilizer with a high water holding capacity so it was able to retain juices in the sausages even after cooking [26] [66]. Springiness was highest in the sample with 20% quinoa and 3% gum Arabic while that with 0% quinoa and 3% gum had the lowest. Quinoa flour influenced springiness due to higher amounts of proteins that denature and interact with each other and fat, forming a gel-like matrix adding to springiness of the samples [62]. Cohesiveness was highest in the sample with 0% quinoa and 0% gum while it was lowest in the sample with 60% quinoa and 2% gum. Cohesiveness may have been lower in other samples because of gum Arabic and quinoa flour addition. Gumminess was highest in the sample with 80% quinoa and 0% gum and the least was the sample with 0% quinoa and 4% gum. Quinoa flour increased gumminess whereas gum Arabic decreased it. This is attributed to the fact that quinoa flour contains globulins and albumins that form a resilient network with pork proteins leading to increased gumminess [63]. The sample with 80% quinoa and 0% gum recorded the highest chewiness whereas the sample with 0% quinoa and 3% gum recorded the least. Gum Arabic's ability to retain juices in sausages gives a smoother texture leading to less gummy and chewy sausages.

**Table 3.** Effect of Quinoa and gum Arabic substitution levels on textural properties of pork sausages.

Quinoa (%)	Gum (%)	Hardness (N)	Springiness (N-)	Cohesiveness (N.mm-)	Gumminess (Nm)	Chewiness (Nm/m <sup>3</sup> )	Resilience
0	0	6720.89 ± 321.27 <sup>efg</sup>	0.86 ± 0.02 <sup>ab</sup>	0.62 ± 0.04 <sup>a</sup>	4158.74 ± 454.30 <sup>bcd</sup>	3561.60 ± 367.48 <sup>bc</sup>	0.29 ± 0.03 <sup>a</sup>
	1	2568.37 ± 207.39 <sup>lm</sup>	0.70 ± 0.02 <sup>ef</sup>	0.41 ± 0.01 <sup>def</sup>	1055.19 ± 99.49 <sup>j</sup>	741.50 ± 85.30 <sup>l</sup>	0.13 ± 0.00 <sup>ef</sup>
	2	3187.49 ± 478.73 <sup>klm</sup>	0.75 ± 0.01 <sup>abcdef</sup>	0.44 ± 0.01 <sup>def</sup>	1388.75 ± 206.62 <sup>ij</sup>	1048.79 ± 162.37 <sup>kl</sup>	0.15 ± 0.00 <sup>def</sup>
	3	2766.93 ± 85.17 <sup>lm</sup>	0.66 ± 0.04 <sup>f</sup>	0.39 ± 0.01 <sup>ef</sup>	1082.75 ± 55.07 <sup>j</sup>	712.58 ± 53.21 <sup>l</sup>	0.12 ± 0.01 <sup>f</sup>
	4	2489.78 ± 198.41 <sup>m</sup>	0.73 ± 0.01 <sup>bcdef</sup>	0.40 ± 0.00 <sup>def</sup>	1000.68 ± 83.38 <sup>j</sup>	734.00 ± 59.86 <sup>l</sup>	0.13 ± 0.00 <sup>ef</sup>
20	0	3440.38 ± 265.56 <sup>klm</sup>	0.76 ± 0.01 <sup>abcdef</sup>	0.49 ± 0.01 <sup>bcde</sup>	1691.84 ± 157.58 <sup>hij</sup>	1290.37 ± 138.14 <sup>ijkl</sup>	0.18 ± 0.01 <sup>cdef</sup>
	1	5714.10 ± 107.25 <sup>ghi</sup>	0.84 ± 0.02 <sup>abc</sup>	0.44 ± 0.04 <sup>cdef</sup>	2532.77 ± 195.20 <sup>fghi</sup>	2138.25 ± 208.10 <sup>fghijk</sup>	0.15 ± 0.02 <sup>def</sup>
	2	6401.77 ± 583.70 <sup>efgh</sup>	0.83 ± 0.01 <sup>abcd</sup>	0.44 ± 0.01 <sup>def</sup>	2790.78 ± 248.62 <sup>efgh</sup>	2334.61 ± 229.98 <sup>efghi</sup>	0.14 ± 0.01 <sup>ef</sup>
	3	5786.71 ± 365.78 <sup>fghi</sup>	0.88 ± 0.02 <sup>a</sup>	0.48 ± 0.01 <sup>bcde</sup>	2801.24 ± 180.23 <sup>efgh</sup>	2454.22 ± 107.06 <sup>defgh</sup>	0.17 ± 0.00 <sup>cdef</sup>
	4	4788.15 ± 63.61 <sup>hijk</sup>	0.75 ± 0.02 <sup>abcdef</sup>	0.48 ± 0.02 <sup>bcde</sup>	2297.96 ± 68.66 <sup>fghi</sup>	1711.99 ± 39.45 <sup>ghijkl</sup>	0.17 ± 0.01 <sup>cdef</sup>

## Continued

40	0	5434.74 ± 125.90 <sup>ghij</sup>	0.81 ± 0.02 <sup>abcde</sup>	0.50 ± 0.02 <sup>bcd</sup>	2735.08 ± 152.98 <sup>efgh</sup>	2231.94 ± 163.38 <sup>efghij</sup>	0.20 ± 0.01 <sup>bcd</sup>
	1	6614.99 ± 280.39 <sup>efg</sup>	0.78 ± 0.03 <sup>abcdef</sup>	0.45 ± 0.02 <sup>cdef</sup>	3013.75 ± 268.19 <sup>defg</sup>	2355.27 ± 303.34 <sup>efghi</sup>	0.15 ± 0.01 <sup>def</sup>
	2	9082.28 ± 505.55 <sup>bc</sup>	0.85 ± 0.02 <sup>abc</sup>	0.49 ± 0.02 <sup>bcd</sup>	4500.99 ± 383.85 <sup>bc</sup>	3822.26 ± 361.79 <sup>b</sup>	0.18 ± 0.01 <sup>cdef</sup>
	3	4627.83 ± 130.84 <sup>ijk</sup>	0.80 ± 0.01 <sup>abcde</sup>	0.45 ± 0.01 <sup>cdef</sup>	2062.15 ± 37.66 <sup>ghij</sup>	1649.59 ± 49.44 <sup>ghijkl</sup>	0.16 ± 0.01 <sup>def</sup>
	4	4235.03 ± 109.98 <sup>ijkl</sup>	0.72 ± 0.02 <sup>cdef</sup>	0.44 ± 0.01 <sup>cdef</sup>	1871.15 ± 57.71 <sup>ghij</sup>	1356.93 ± 74.25 <sup>hijkl</sup>	0.15 ± 0.01 <sup>def</sup>
60	0	7421.67 ± 408.39 <sup>cdef</sup>	0.83 ± 0.02 <sup>abcd</sup>	0.54 ± 0.02 <sup>abc</sup>	4028.95 ± 327.55 <sup>bcd</sup>	3367.23 ± 338.15 <sup>bcd</sup>	0.22 ± 0.01 <sup>bc</sup>
	1	6764.27 ± 444.17 <sup>defg</sup>	0.78 ± 0.02 <sup>abcdef</sup>	0.44 ± 0.01 <sup>cdef</sup>	2978.83 ± 193.60 <sup>defg</sup>	2329.10 ± 143.79 <sup>efghi</sup>	0.16 ± 0.01 <sup>def</sup>
	2	4634.00 ± 296.42 <sup>ijk</sup>	0.71 ± 0.03 <sup>def</sup>	0.37 ± 0.01 <sup>f</sup>	1699.84 ± 139.14 <sup>hij</sup>	1215.08 ± 150.46 <sup>ijkl</sup>	0.13 ± 0.01 <sup>ef</sup>
	3	8435.92 ± 206.70 <sup>bcd</sup>	0.79 ± 0.01 <sup>abcde</sup>	0.45 ± 0.02 <sup>cdef</sup>	3834.31 ± 197.69 <sup>bcd</sup>	3034.50 ± 154.66 <sup>bcd</sup>	0.17 ± 0.01 <sup>cdef</sup>
	4	5570.40 ± 62.41 <sup>ghi</sup>	0.77 ± 0.02 <sup>abcdef</sup>	0.42 ± 0.02 <sup>def</sup>	2328.51 ± 85.59 <sup>efghi</sup>	1802.42 ± 69.68 <sup>ghijkl</sup>	0.14 ± 0.01 <sup>def</sup>
80	0	10988.34 ± 463.54 <sup>a</sup>	0.84 ± 0.03 <sup>abc</sup>	0.57 ± 0.01 <sup>ab</sup>	6224.21 ± 332.48 <sup>a</sup>	5244.02 ± 230.09 <sup>a</sup>	0.26 ± 0.00 <sup>ab</sup>
	1	10057.99 ± 228.53 <sup>ab</sup>	0.77 ± 0.04 <sup>abcdef</sup>	0.47 ± 0.01 <sup>bcd</sup>	4776.85 ± 127.21 <sup>b</sup>	3682.39 ± 282.26 <sup>bc</sup>	0.18 ± 0.01 <sup>cde</sup>
	2	7465.97 ± 172.57 <sup>cde</sup>	0.81 ± 0.02 <sup>abcde</sup>	0.45 ± 0.01 <sup>cdef</sup>	3333.23 ± 20.31 <sup>b</sup>	2702.84 ± 57.84 <sup>cdefg</sup>	0.17 ± 0.01 <sup>cdef</sup>
	3	9337.65 ± 180.68 <sup>ab</sup>	0.78 ± 0.01 <sup>abcdef</sup>	0.49 ± 0.03 <sup>bcd</sup>	4537.81 ± 315.98 <sup>cdef</sup>	3554.68 ± 226.38 <sup>bcd</sup>	0.18 ± 0.02 <sup>cdef</sup>
	4	3867.52 ± 298.08 <sup>ijklm</sup>	0.71 ± 0.04 <sup>def</sup>	0.43 ± 0.03 <sup>def</sup>	1656.75 ± 225.44 <sup>hij</sup>	1189.96 ± 225.63 <sup>ijkl</sup>	0.16 ± 0.02 <sup>def</sup>

Data is presented as mean ± standard error. Means along the column followed by different superscript letters are significantly different ( $p < 0.05$ ).

## 4. Conclusion

The results indicate that using different levels of gum Arabic and partial fat substitution with quinoa flour had significant effects on the physicochemical and textural properties of the pork sausages. Quinoa led to improved nutritional value in the sausages since it significantly increased the amount of crude protein from  $11.32\% \pm 0.22\%$  to  $19.12\% \pm 0.59\%$  and significantly decreased fat content from  $32.14\% \pm 0.49\%$  to  $9.06\% \pm 0.92\%$  in the sausages. Incorporating gum Arabic prevented the sausages from hardening thus their textural properties were improved as predicted. Understanding the functionality of gum Arabic and quinoa in meat products will permit their utilization in the food industry. This research has shown that using quinoa flour and gum Arabic in pork sausages can improve their physicochemical and textural attributes. This information is important because it could be used in value addition of meat and meat products especially sausages as well as enhanced utilization of quinoa and gum Arabic in the food industry. Successful utilization of quinoa and gum Arabic could not only lead to enhanced nutrition but also improve the livelihoods of farmers and stakeholders who will be involved.

## Ethical Approval

The research work was approved by the Egerton University Research Ethics Committee and the National Commission for Science, Technology & Innovation (NACOSTI) of Kenya under Research License Number: NACOSTI/P/24/32960. There

was no experimentation of human subjects in this study.

### Declaration of Competing Interests

The authors declare that they do not have any financial competing interest in regard to this study.

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### Conflicts of Interest

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

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