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ABSTRACT

This study dealt with the use of quinoa flour (QF) or teff flour (TF) as partial beef fat replacers in the formulation of emulsion-type sausages. A control (C) group was manufactured with 20% beef fat, while the other three groups were formulated with 10% beef fat plus 5% QF (Q), 5% TF (T), and 2.5% QF + 2.5% TF (QT). Water-holding capacity of the emulsions was higher in Q (81.81%), T (82.20%), and QT (84.10%) samples than in C (64.83%) samples. Total expressible fluid and fat (TEF and EFAT) were the lowest in Q and T samples, indicating the highest emulsion stability of those groups. Incorporation of QF and TF into formulations increased moisture and carbohydrate contents while decreased fat and energy values. Besides, the use of QF was effective to increase protein and dietary fiber contents. T samples had lower luminosity (L*) and higher yellowness (b*) than C sausages, whilst Q sausages did not result in significant color changes. Higher cook yield values were recorded in Q (97.96%), T (98.21%), and QT (98.15%) samples compared with C (96.44%) samples. Inclusion of QF and TF to formulation led to lower hardness and gumminess, while utilization of TF was also effective to decrease chewiness. Consequently, healthier emulsified sausages were obtained by the inclusion of quinoa or teff flours that could decrease the fat content more than 50% without sacrificing overall quality, bringing advantages by quinoa over teff for increasing nutritional value and leading minimal modifications on color and texture.

Keywords: emulsified sausage, reduced-fat meat products, quinoa, teff, fiber source ingredients

INTRODUCTION

In our modern world, rising attention has been paid to specific types of healthy and beneficial food ingredients since consumers are becoming more and more health-conscious about the foodstuff they eat (Öztürk and Serdaroğlu, 2017). Although muscle foods are one of the essential sources of high-quality protein and many bioactive compounds; the high fat and saturated fatty acid content of meat products make them avoidable foods for health since they could trigger the risk of serious degenerative and chronic diseases (Carvalho et al., 2019; Cofrades et al., 2017; Jiménez-Colmenero et al., 2015). Hence, one of the most useful strategies to produce meat products concerning health is to reformulate them to contain a reduced amount of total fat.

Olmedilla-Alonso et al. (2013) classified the three main aims of fat reduction and/or modification strategies in meat products as i) reduction of saturated fat amount, ii) reduction of cholesterol and iii) modification of fatty acid composition. Within these strategies, total fat reduction in meat products are basically based on two applications: The first application is to use lean meat cuts as raw materials (Carvalho et al., 2019), which is probably the simplest way but it might increase costs in processed meat products. The second way is to replace the animal fat with water plus a non-meat ingredient (proteins, carbohydrates, hydrocolloids, or dietary fibers) that brings a functional appeal and compensate for the quality losses caused by the absence of fat (Carvalho et al., 2019; Cofrades et al., 2017; Olmedilla-Alonso et al., 2013). Since fat is one of the major components in meat product formulations that has considerable impacts on texture, flavor, eating satiety, and cook yield; the reduction of fat is a big technological challenge due to the probability of deteriorated texture, undesired sensory characteristics, and losses in product yield (Han and Bertram, 2017; Öztürk and Serdaroğlu, 2017). However, these problems in the final products could be minimized due to the excellent functional properties of fiber-rich ingredients. Thus, an important aspect of designing low-fat meat products is utilizing dietary fiber sources as fat replacers that could maintain quality meanwhile could contribute to healthy eating.

Quinoa (*Chenopodium quinoa* Willd.) is a very popular seed crop used in the development of functional foods, that has high amounts of dietary fiber, minerals, and excellent protein content with nine essential amino acids (Kahlon and Chiu, 2015; Özer and Seçen, 2018). Pellegrini et al. (2018) stated that quinoa seeds represent an interesting research field for producing ingredients to increase the level of macromolecules and phytochemicals particularly in meat products. Teff (*Eragrostis tef*) is a tropical cereal that is the only cultivated species within its genus (Gebremariam et al., 2014). Teff flour is rich in fiber, a set of essential amino acids, and minerals with its high technological properties that allow it to be used in different food applications (Campo et al., 2016). According to the mentioned data, these two pseudo-cereals seem to have good application potential in the formulation of low-fat meat products with their great nutritional and health-promoting properties. Until now, utilization of quinoa ingredients was reported to improve quality characteristics of some meat products such as goat meat nuggets (Verma et al., 2019), beef burgers (Baioumy et al., 2018) and bologna-type sausages (Fernández-López et al., 2020). To our knowledge, no studies dealing with the utilization of teff flour or the simultaneous use of quinoa and teff flours in reduced-fat sausage formulations have yet been published. In the present work, it was targeted to investigate the emulsion stability parameters, visual and textural characteristics and yield of beef sausages formulated with quinoa or teff flours (alone or in tandem) as partial beef fat replacers.

MATERIALS AND METHODS

Material

Post-rigor beef (*M. semitendinosus*) (72.8% moisture, 20.6% protein, 4.4% fat, and 2.1% ash) and beef fat were purchased from a local butcher and transported to laboratory maintaining the cold chain. Quinoa flour (QF), consisted of 58% carbohydrate, 14.5% protein, 12.3% dietary fiber, 10.2% water, 6.8% lipid, and 1.8% ash was supplied from Naturelka Co. (Aydın). Teff flour (TF), consisted of 65.4% carbohydrate, 12.3% protein, 11.5% water, 7.9% dietary fiber, 2.1% lipid, and 0.8% ash was purchased from Nustil-Nutrition Style Co. (İstanbul). The spices used in sausage formulations were purchased from the local market and other food additives were supplied from A&D Chemicals (Istanbul). All the chemicals utilized in the analysis were analytical grade and were used without further purification.

Experimental design and sausage manufacture

Table 1 presents the formulas of the sausage treatments. Totally four different treatments were produced as follows: Control (C group) treatment was formulated to contain 70% meat, 20% beef fat, and 10% water, while the other samples were formulated to contain 70% meat, 10% total fat, and 20% water with the addition of 5% QF (Q group), 5%TF (T group) or 2.5% QF + 2.5% TF (QT group). Thus, total fat content was reduced from 20% to 10% in samples containing those flours. The amounts of the other ingredients were calculated based on the total amount of meat, fat, and water.

For the production of the sausages, initially, all subcutaneous fat and visible connective tissue were removed from the meat. After that, meat and beef fat were separately minced through a 3 mm plate. Before the addition of meat, beef fat was pre-emulsified with soy protein, sodium caseinate, and one-fourth of the ice in a bowl cutter (Alpina-SC, Switzerland) operated at 1000 rpm for 3 min. After that, minced meat, curing agents, and ice were added and emulsified with fat at 2000 rpm for 5 min. Finally, the spice mix, the rest of the ice, or the mentioned flours were added and mixed at 1000 rpm for 3 min. No other binders were further included to the formulations to clearly follow up the impacts of QF and TF. The final sausage emulsion was transferred to a filling machine (Alpina-SC, Switzerland) and embedded in collagen sausage casings (19 mm, Viscofan, Spain). The sausages were then smoked in a smoking chamber (AFOS Mini Klins, UK) at 45°C for 105 min and thereafter cooked in a steam-jacketed stainless steel boiler operated at 80°C until the core temperature reached to 72°C. As soon as the heat treatment finished, the samples were cooled to room temperature. The emulsion samples were immediately subjected to related analysis, while the analysis of the final products was performed within 72 hours after production.

Analysis

Water holding capacity

Water holding capacity (WHC) of the sausage emulsions was determined according to Hughes et al. (1997) with modifications. 10 g emulsion was weighed (W_1), posed into glass jars and hold in 90°C water bath for 10 min. After that, the samples were cooled to room temperature and were wrapped in cotton gauze fabric and centrifuged at 1400 rpm (NF400, Nüve, Turkey) for 15 min and weighed again (W_2). WHC was calculated from the equation below:

$$WHC\ \% = 1 - T/M * 100 = 1 - (W_1 - W_2)/M * 100$$

(T: Water loss after heating and centrifugation, M: Total moisture content of the sample)

Emulsion stability

Twenty-five g of the sample was centrifuged for 1 min at 4000 rpm (NF400, Nüve, Turkey). The samples were heated in a water bath at 70℃ for 30 min and centrifuged again for 3 min at 4000 rpm. The pellet was weighed while the supernatant was transferred to a crucible and dried for 12 hours at 100℃. Total expressible fluid (TEF) and expressible fat (EFAT) were calculated to express emulsion stability (ES) using the equations below: (Hughes et al., 1997)

$$TEF = (W_{centrifuge\ tube} + W_{sample}) - (W_{centrifuge\ tube} + W_{pellet})$$

$$TEF\ (\%) = TEF / W_{sample} \times 100$$

$$EFAT\ (\%) = [(W_{crucible} + W_{dried\ supernatant}) - (W_{empty\ crucible})] / TEF \times 100$$

Chemical composition and pH

Total moisture (AOAC, 2012), protein (LECO nitrogen analyzer, FP528, USA), fat (Flynn and Bramblett, 1975), and ash (AOAC, 2012) content of the sausages were analyzed to specify the proximate composition. Rest of the chemical components was considered to be made up of carbohydrate. The dietary fiber content of the samples that contain QF or TF was estimated based on the dietary fiber content (specified by the supplier) and inclusion amounts of the flours. Energy value was calculated from the chemical composition based on 100 g sample using Atwater values for fat (9 kcal/g), protein (4.02 kcal/g), and carbohydrate (3.87 kcal/g) (Mansour and Khalil, 1997). pH value of the samples was measured with a pH-meter (pH 330i/SET; WTW, Germany) equipped with a penetration probe.

Instrumental Color

The surface color of the sausages was measured using a portable colorimeter (CR-200, Konica Minolta, Japan) with a D65 illuminant setting and a 10° standard observer and expressed as CIE luminosity (L*), redness (a*), and yellowness (b*). White and black standard plates were used for calibration.

Cook yield

Cook yield of the sausages was analyzed according to Murphy et al. (1975) by measuring the weight before and after cooking in boiling water until the core temperature reached to 72℃ and calculated according to the equation below:

Cook yield (%) = $[(W_{cooked\ sausages}) / (W_{uncooked\ sausages})] \times 100$

Texture profile analysis

The instrumental texture profile analysis (TPA) was carried out with a texture analyzer (TA-XT2, Stable Micro Systems, Haslemere, UK). Samples as cylindrical cubes (diameter: 1 cm, height: 1 cm) were compressed to 50% of their original height with a crosshead speed of 2 mm/s and 30 kg load cell. A pre-test speed of 2 mm/s and a post-test speed of 5 mm/s were applied. Hardness, cohesiveness, gumminess, and chewiness of the samples were calculated from the force and time curves.

Statistical analysis

Data were statistically analyzed by utilizing SPSS for Windows (version 20.0, IBM, USA) by one-way analysis of variance (ANOVA). The trial was replicated twice (two independent batches), with each replication corresponding to a different production day. For each batch of the sausages, measurements of related traits were carried out in triplicate.

In the mixed model, all the quality parameters evaluated for the trials were considered as dependent variables, four different formulations were included as fixed effects, and the two replications of the trial were included as random effect. Duncan's multiple range test was utilized to specify the significant differences among means at a 95% confidence interval. Data was expressed as the mean ± standard deviation.

RESULTS AND DISCUSSION

Emulsion characteristics

WHC is known as the ability of meat to retain moisture, while ES term refers to the capability of the emulsion to resist changes in its features over time (Öztürk and Serdaroğlu, 2018). The results of WHC and ES of sausage emulsions are shown in Figures 1a and 1b, respectively. The lowest WHC was recorded in full-fat control samples ($p<0.05$). Compared to C samples, strong evidence of a rise in WHC was found when QF, TF, or a mixture of those were included in the formulation ($p<0.05$). The most probable reason for this increase in WHC is the contribution of the fibers and other complex carbohydrates (starches) present in the related flours that aided more water retention in the emulsion. Mun et al. (2006) emphasized that the improvement of WHC may be attributed to the fact that the fat globules and myofibrillar proteins are surrounded and covered by the fibers to prevent fluid leakage during cooking. In like manner, ES parameters which were expressed as TEF and EFAT were significantly lower in Q and T samples compared with C samples ($p<0.05$). This data was a good indicator of the high ES of these samples since the total amount of the fluids released from the emulsion structure was substantially small. Similar data was reported by Fernández-López et al. (2020) who found that the use of both quinoa seeds and its fiber-rich fraction as binder replacers positively affected ES of bologna-type sausages. In another study, it was found that increased amounts of quinoa paste were effective to reduce TEF and thus to increase the stability of reduced-fat meat pâté (Pellegrini et al., 2018). The data of Schmiele et al. (2015) indicated that the inclusion of amorphous cellulose fiber in reduced-fat meat model systems resulted in ES similar to that found for the standard samples. Getting back to our results, interestingly, a different trend in ES was observed in QT samples, in which both TEF and EFAT values were not as low as Q and T samples, thus the stability was lower, probably due to the weak interactions of different flours when used together. Thus, it could be said that using these flours one by one rather than using them simultaneously would increase the stability features of the emulsions. Nonetheless, no significant differences were noted between ES parameters of QT and C sausages, meaning that this group was capable of holding the stability similar to full-fat samples.

Chemical composition and pH

The chemical composition of the samples in terms of total moisture, protein, fat, ash, and dietary fiber content is presented in Table 2. Adding both flours to the sausage formulations significantly increased the total amount of moisture compared to control samples ($p<0.05$), which could be attributed to higher water concentrations used in these formulations as well as desired water binding ability provided by the added flours. Compared to TF, QF was noted to be more effective in increasing moisture content ($p<0.05$), which could be due to the higher protein and dietary fiber content of this flour that led more water to be entrapped in the meat matrix. Similarly, dos Santos Alves et al. (2016) detected an increment in the moisture content of sausages produced with green banana flour gels as fat replacers. It was observed that the protein content of the sausages containing QF was significantly higher compared to the protein content of C group (p<0.05). The protein amount in QF was reported to be quite high (14.5%) according to the manufacturer's specifications. In this case, it can be said that it is possible to enhance the nutritional value of reduced-fat sausages formulated with QF. Similar data was reported by Baioumy et al. (2018) who detected an increase in the protein content of beef burgers with increased amounts of QF. As expected, the total amount of fat in all of the fat-reduced sausage samples was significantly lower than full-fat C samples (p<0.05). Since the reduction ratio of fat in most of the groups was more than 50%, all the products with QF, TF, or their mixture could be referred to as "reduced-fat" according to European legislation (European Parliament, 2006). Our results agreed with the reports for emulsion-type sausages concerning the substitution of animal fat with non-meat ingredients such as cereal flours (Yang et al., 2009), green banana flour (dos Santos Alves et al., 2016) and wheat fiber (Choe and Kim, 2019). When the effect of different flours on fat content is examined, it was observed that the fat content of the samples containing QF was lower than the fat content of the samples containing TF (p<0.05). The probable reason for this situation may be the high water and protein content of the Q group that led the fat content to be decreased proportionally. Ash content of the samples did not differ from each other, meaning that the inclusion of the flours to sausage formulations were not effective to alter the inorganic material content.

Among treatments, the lowest carbohydrate content belonged to control sausages (p<0.05), that was an expected result since no flour (no additional carbohydrate source) was incorporated into the formulation of this group. Carbohydrate content of the samples containing QF or TF did not statistically differ from each other. The amount of dietary fiber, which was proportionally calculated based on the total dietary fiber present in the flours and their inclusion amount, was recorded to be the highest in Q samples, which was due to the high dietary fiber content of QF (12.25%). Kehlet et al. (2017) stated that a food product must achieve a minimum dose of 3 g of dietary fiber per 100 g in order to make the nutritional claims “food fiber source”. This information indicates that the inclusion amounts of the fibers should be maximized to supply the mentioned doses to the extent allowed by the product’s technology. In concordance with total fat amounts, the lowest energy value among the treatments were recorded in Q samples, while the energy value of T and QT samples were also lower than C samples, most probably due to the decreased fat amount in these samples ($p<0.05$). In samples formulated with QF, total calories were reduced by nearly 50%, while in other samples the reduction ratios were more than 30%. These results showed that all the low-fat treatments could be considered as “energy-reduced” products according to European Regulation (European Parliament, 2006). Similarly, Kaack and Pedersen (2005) detected that the increased substitution of fat by potato fiber and water decreased the energy content of liver patés. Eventually, since the incorporation of QF was very effective to decrease fat content and increase both protein and dietary fiber contents, the use of this ingredient was noted to be a predominant choice to enhance the nutritional profile of low-fat sausages. pH values of the sausages ranged between 5.93-5.98. Among samples, the highest pH value belonged to C samples ($p<0.05$), meantime the rest of the samples had similar pH. Méndez-Zamora et al. (2015) obtained similar results to our data; they reported that increased concentrations of inulin plus pectin as fat replacers resulted in a drop in pH values of frankfurters, which was associated with the low pH of pectin. In contrast to these results, Choe and Kim (2019) noted that pH values of chicken sausages were not affected by using chicken skin and wheat fiber mixture as fat replacers. In another study, sausages containing pork skin and green banana flour as fat replacers had similar pH value to full-fat samples (dos Santos

Alves et al., 2016). The differences obtained from those studies could be due to the acidity and alkalinity of the materials added to the meat product formulation (Serdaroğlu et al., 2018).

Instrumental color

Reducing the amount of fat in meat product formulations and the use of non-meat ingredients may cause some changes in the visual properties of the product. Therefore, it is necessary to evaluate the effects of these changes on the color of the final product, which is a crucial quality feature on consumer choices. Table 3 shows the results of color measurement in terms of luminosity (L*), redness (a*), and yellowness (b*) values. Compared with C samples, it was determined that the group that caused the least change in color was the Q group, where all the measured color attributes were similar to full-fat samples. Besides, utilization of TF alone or in combination with QF led significant decrements in L* values of the sausages ($p<0.05$), that was probably arose from the natural characteristics of TF giving a darker color when dissolved in an aqueous medium. The addition of TF also resulted in a significant increase in b* values of the samples compared with C sausages ($p<0.05$), which might be a consequence of the presence of natural yellow pigments in this flour. Despite the changes seen in L* and b* values with TF addition, no significant differences were detected in a* values among treatments. Previously, Schmiele et al. (2015) assessed the replacement of pork fat by amorphous cellulose fiber in cooked meat systems and found that the color parameters were not significantly affected except the change in b* values during storage. Yang et al. (2009) reported that the addition of some cereal flours like wheat, millet, and barley to low-fat duck meat sausages decreased L* and a* values while the addition of barley flour increased b* values. These results suggested that different components used in the formulation might cause different influences on the color of the final product. Furthermore, in the study of Choe and Kim (2019), it was underlined that the color difference between full-fat and fat-replaced sausage treatments was not detected in the sensory panel due to the small numerical variances.

Cook yield

Cook yield in meat products is an important quality factor that significantly affects both the sensory and textural quality parameters of the final product as well as its cost. Since fat is closely related to the weight loss during cooking and eating quality of meat products after cooking, precautions should be taken to reduce cook losses in low-fat meat products. One of the actions to reduce the losses is the incorporation of dietary fibers to the formulation that enhance the binding properties and thereby prevent the release of fluid from the structure. Cook yield values of the sausages confirmed this action (Figure 2), seeing that the use of QF and TF alone or in tandem was effective to increase the yield of low-fat sausages. The values were found between 96.4±0.49 - 98.2±0.07 %, the lowest yield was recorded in full-fat C samples whilst all the low-fat samples had a higher yield than control sausages ($p<0.05$). These results confirmed the high ability of QF and TF to hold water in the meat matrix upon heat treatment. Schmiele et al. (2015) stated that the addition of water in low-fat treatments could increase the cooking loss by increased exudation because of weakened emulsification stability. Despite this, in our study, QF and TF were noted as compelling materials that could prevent cooking loss and improve the yield of the sausages even so the total fat amount was reduced in half. In a similar study performed with fat-reduced meat model systems, it was reported that the addition of dietary fibers such as cellulose, chitosan, or pectin managed to decrease cooking loss by favoring water-binding potential and fat absorption, while the addition of inulin did not change the cook loss compared with control (Han and Bertram, 2017). Likewise, Petersson et al. (2014) found that the process loss of low-fat sausages with oat bran was lower than the process loss of the sausages with rye bran or barley fiber, due to the gelling ability of oat bran upon heating. That study pointed out that the processing yield could exhibit variations depending on the type of fiber and its functional characteristics. According to our results, it was observed that QF and TF treatments had similar cooking yield, thus it could be said that these flours showed equivalent functions in terms of cooking characteristics in the meat system.

Texture profile analysis

The possible changes in textural properties as a result of the reduction of fat in meat product formulations is another factor to be considered to follow up the quality. The textural parameters of the sausages are set out in Table 3. Utilization of QF, TF, or their combination led to significant decrements in hardness ($p<0.05$), which might be due to the increase in free water content of the reduced-fat formulations aided by high water binding ability of the fiber source ingredients that eventually resulted in a softer structure. Correspondingly, gumminess of the low-fat samples (Q, T, and QT) were lower than C samples ($p<0.05$), meaning that those groups had weaker internal bonds due to the softer network. In accordance with our results, Ö zer and Seçen (2018) recorded decrements in hardness and gumminess of beef burgers with increased concentrations of QF, that was ascribed to the hydro-chemical and physical characteristics of the material. Similar outputs were also recorded in a study concerning the addition of cereal flours to duck meat sausages, where the reductions in hardness and gumminess values were explained by the higher water absorption capacity of the flours when heated (Yang et al., 2009). Q and QT samples had higher cohesiveness compared with other treatments ($p<0.05$), which was possibly due to the spongy network formed by the high dietary fiber content of QF as well as its impact on protein-protein interactions that increased the work done between compressions of the sample. Although chewiness of the samples with TF was lower than the chewiness of C samples ($p<0.05$), Q samples and C samples had similar chewiness, that might be associated with the protein amount of QF leading the samples being chewy.

CONCLUSION

Today two useful strategies for minimizing the unfavorable impacts related with meat products are to reduce the amount of animal fat and to introduce healthier ingredients to formulations. The present study aimed to apply these strategies in emulsion-type sausages produced with the incorporation of quinoa flour, teff flour, or their mixture as partial beef fat replacers. The overall results highlighted the possible inclusion potential of those flours to reduce animal fat, with improving functional properties of the emulsions and thereby leading enhancement in technological quality. In addition, quinoa had some advantages over teff in terms of increasing protein and dietary fiber content, and leading minimal modifications on color and texture. Future studies should seek to identify the use of the mentioned flours as different forms (gelled or pre-emulsified) in the formulations of different meat products (fermented or restructured).

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Table 1. Formulations of sausage treatments

Treatment	Beef (%)	Beef fat (%)	Ice (%)	Pre-emulsion agents (%)	QF (%)	TF (%)	Curing agents (%)	Spice mix (%)
C	70.0	20.0	10.0	4.0	0.0	0.0	3.07	1.2
Q	70.0	10.0	20.0	4.0	5.0	0.0	3.07	1.2
T	70.0	10.0	20.0	4.0	0.0	5.0	3.07	1.2
QT	70.0	10.0	20.0	4.0	2.5	2.5	3.07	1.2

C: Sausages formulated with 20% fat and no flour addition, **Q:** Sausages formulated with 10% fat and 5% QF addition, **T:** Sausages formulated with 10% fat and 5% TF addition, **QT:** Sausages formulated with 10% fat and 2.5% QF + 2.5% TF addition. **QF:** Quinoa flour, **TF:** Teff flour.

The amount of all the ingredients and additives were calculated based on the total amount of beef, beef fat, and ice. **Pre-emulsion agents:** 2.5% soy protein, 1.5% sodium caseinate, **Curing agents:** 2.5% salt, 0.25% saccharose, 0.15% sodium tripolyphosphate (STPP), 0.15% ascorbic acid, and 0.015% sodium nitrite. **Spice mix:** 0.3% sweet red pepper, 0.3% coriander, 0.3% white pepper, 0.15% black pepper, and 0.15% ginger.

Table 2. Chemical composition, total energy, and pH of the sausages

Treatments	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)	Dietary fiber* (%)	Energy value (kcal/100g)	pH
C	59.49^{c} ±0.46	15.89^{b} ±0.40	20.05^{a} ±1.09	3.59 ±0.30	0.98^{b} ±0.38	0.00	248.13^{a} ±4.86	5.98^{a} ±0.01
Q	64.59^{a} ±1.46	17.61^{a} ±1.30	7.96^{c} ±0.33	3.64 ±0.07	6.20^{a} ±1.31	1.57	158.36^{d} ±6.87	5.94^{b} ±0.01
T	62.40^{b} ±0.64	17.05^{ab} ±0.55	10.72^{b} ±0.92	3.40 ±0.05	5.47^{a} ±0.92	0.96	189.94^{b} ±4.96	5.93^{b} ±0.01
QT	64.48^{a} ±0.24	16.37^{ab} ±0.10	9.55^{bc} ±0.99	3.59 ±0.07	4.73^{a} ±0.84	1.28	175.04^{c} ±6.10	5.94^{b} ±0.01

C: Sausages formulated with 20% fat and no flour addition, **Q:** Sausages formulated with 10% fat and 5% QF addition, **T:** Sausages formulated with 10% fat and 5% TF addition, **QT:** Sausages formulated with 10% fat and 2.5% QF + 2.5% TF addition. abcd: Means with the different letter in the same column are significantly different ($p<0.05$).

*Dietary fiber content was proportionally calculated in dry matter over the amount of flours added to the product formulation.

Table 3. Color and texture parameters of the sausages

	Color attributes			Texture profile			
Treatments	L*	a*	b*	Hardness (N)	Cohesiveness	Gumminess (N)	Chewiness (N x mm)
C	43.51^{a}±1.42	15.37±0.61	14.38^{b}±0.37	37.44^{a}±6.41	0.64^{b}±0.01	23.62^{a}±3.55	20.32^{a}±3.50
Q	42.93^{a}±0.76	15.33±0.60	15.04^{ab}±0.53	29.04^{b}±2.30	0.68^{a}±0.01	19.73^{b}±1.38	17.93^{ab}±1.50
T	39.43^{c}±0.45	15.75±0.35	15.44^{a}±0.59	28.45^{b}±2.78	0.64^{b}±0.01	18.24^{b}±1.63	16.29^{b}±1.37
QT	41.13^{b}±0.72	16.37±1.17	14.74^{ab}±0.62	26.96^{b}±1.22	0.67^{a}±0.01	18.00^{b}±0.61	16.32^{b}±0.72

C: Sausages formulated with 20% fat and no flour addition, **Q:** Sausages formulated with 10% fat and 5% QF addition, **T:** Sausages formulated with 10% fat and 5% TF addition, **QT:** Sausages formulated with 10% fat and 2.5% QF + 2.5% TF addition. Different letters in the same column indicate significant difference (p<0.05).

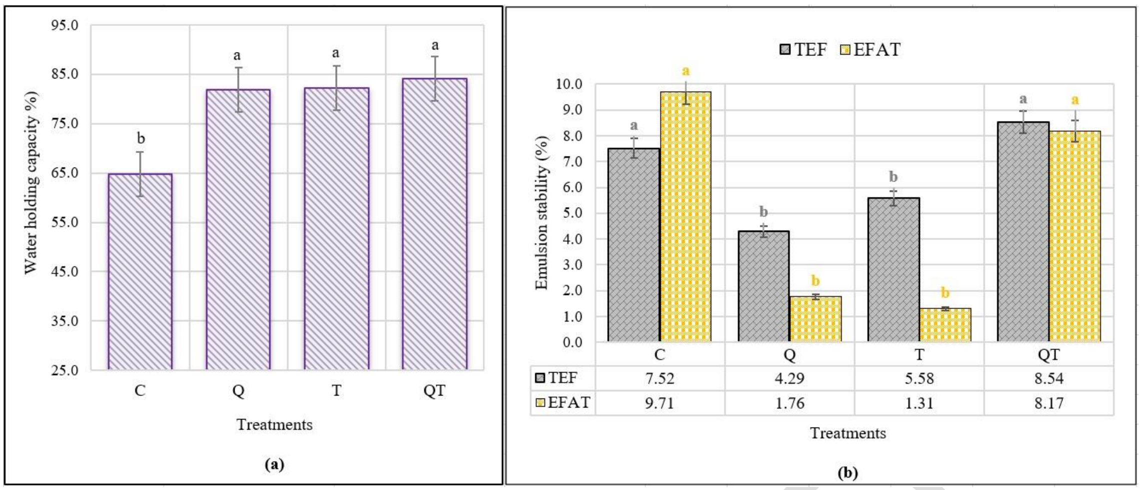

Figure 1(a). Water-holding capacity (WHC) and 1(b). Emulsion stability (ES) in terms of total expressible fluid (TEF) and expressible fat (EFAT) of sausage emulsions

C: Sausages formulated with 20% fat and no flour addition, **Q:** Sausages formulated with 10% fat and 5% QF addition, **T:** Sausages formulated with 10% fat and 5% TF addition, **QT:** Sausages formulated with 10% fat and 2.5% QF + 2.5% TF addition. Different letters in the same column indicate significant difference ($p<0.05$).

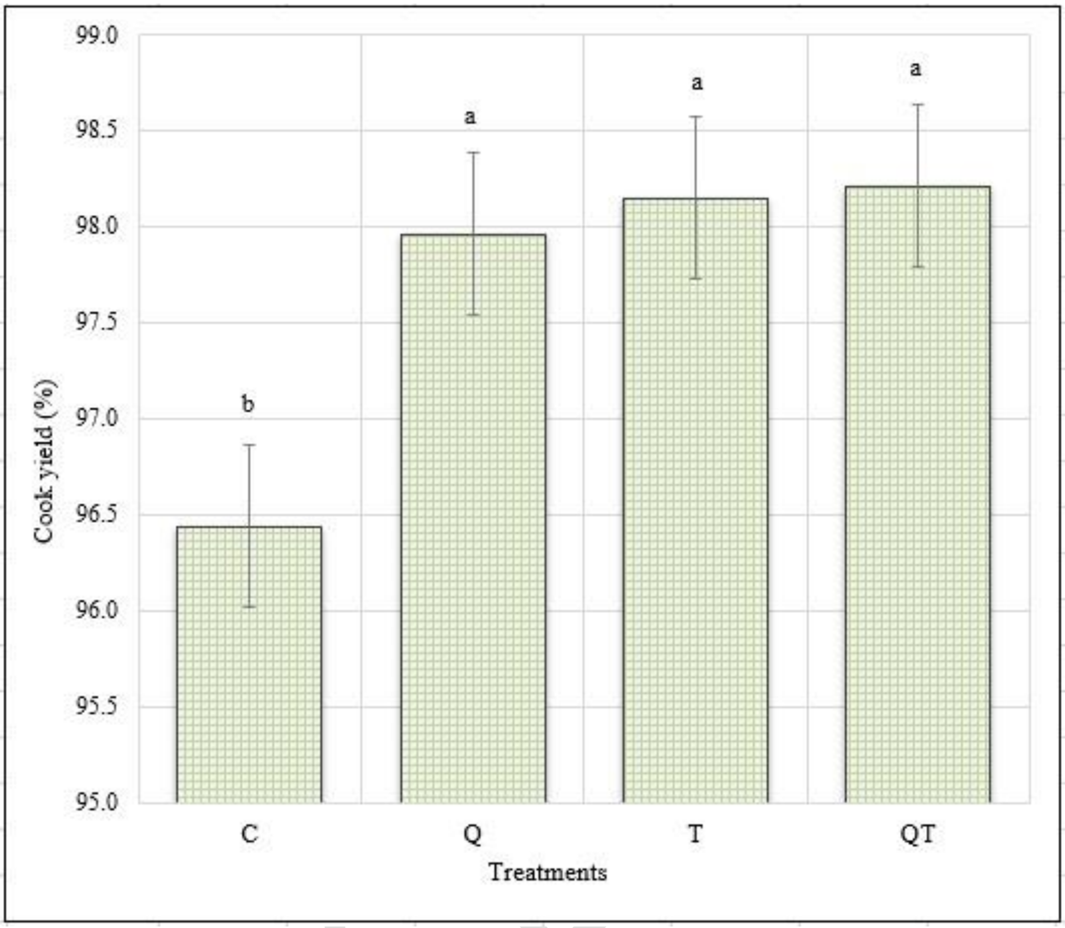

Figure 2. Cook yield of the sausages

C: Sausages formulated with 20% fat and no flour addition, **Q:** Sausages formulated with 10% fat and 5% QF addition, **T:** Sausages formulated with 10% fat and 5% TF addition, **QT:** Sausages formulated with 10% fat and 2.5% QF + 2.5% TF addition. Different letters indicate significant difference ($p<0.05$).