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Chemical and technological properties of bologna-type sausages with added black quinoa wet-milling coproducts as binder replacer

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ABSTRACT

The objective of this study was to evaluate different strategies for adding 3% black quinoa (either as whole seeds or as a fiber-rich fraction of quinoa from its wet-milling process) to bologna-type sausage. This addition was evaluated in terms of its influence on nutritional composition and technological properties (emulsion stability, pH, water activity, color changes, textural properties, residual nitrite level and lipid oxidation). Both strategies resulted in commercially feasible sausages with increased nutritive properties (dietary fiber) and with some modifications in their technological properties. Compared with control sausages, they showed better emulsion stability, lower water activity and lipid oxidation values (interesting properties for sausages shelf-life). Color changes were more evident when the fiber-rich fraction was added. The residual nitrite level increased with the addition of quinoa so that it would be necessary to incorporate less nitrites, or it might even be unnecessary, contributing to the production of more natural products.

1. Introduction

Bologna-type sausages are widely consumed in many countries and are of great economic importance for the meat industry. They are made from beef, pork, chicken or meat mixtures, with the different ingredients and flavorings added, including extenders or binders and fillers. However, due to their high animal fat content (20–30%) and, as a result, high content of saturated fatty acids, these products are heavily criticized by public health authorities, as several studies have demonstrated the association between high consumption of these components and the onset of cardiovascular diseases, some types of cancer, and obesity (NHFA, 2003; Sacks et al., 2017; WHO, 2015).

The development of reformulated meat products has been one of the most frequently used options by the meat industry to meet the growing demand of consumers towards nutritionally healthier products. This can be done mainly in two ways: reducing the content of fats, cholesterol, sodium chloride and nitrites (compounds perceived as unhealthy by consumers) or increasing the content of compounds beneficial for human health. Whatever the case, to ensure acceptability, these meat products should not differ much from traditional meat products (Botez, Nistor, Andronoiu, Mocanu, & Ghinea, 2017; Fernández-López, Lucas-González, Viuda-Martos, et al., 2019).

In this context, quinoa (*Chenopodium quinoa Willd*) offers considerable potential for the development of healthier foods. The high protein content of an equilibrated composition and its gluten-free nature determine the nutritional value of quinoa grain, which meets the FAO/WHO/UNU ideal protein reference pattern for children (WHO, 1985). In addition, quinoa seeds also represent an interesting field of research due to their content in unsaturated lipids (linolenic and linoleic acids), dietary fiber, complex carbohydrates (mainly starch), minerals (iron, copper, manganese, and potassium) and other beneficial bioactive compounds such as carotenoids, vitamin C and polyphenolic compounds (phenolic acids, and flavonoids such as kaempferol and quercetin) (Pellegrini, Lucas-González, Ricci, et al., 2018; Pereira et al., 2019; Wang & Zhu, 2016). Indeed, many studies have described them as protecting against a variety of diseases, particularly cancer, allergies and, inflammatory diseases, and they may reduce the risk of cardiovascular diseases (Gómez-Caravaca, Iafelice, Verardo, Marconi, & Caboni, 2014; Nowak, Du, & Charrondière, 2016). Differences in these properties between the most common color varieties of quinoa (i.e.,

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red, black and white) have been reported (Pellegrini, Lucas-González, Ricci, et al., 2018; Pereira et al., 2019), colored seeds being considered to have a higher potential for applications as ingredients to enrich food systems. Both whole flour, obtained from milling, and whole seed are incorporated in many food matrixes (Ramos-Díaz et al., 2013; Wang & Zhu, 2016). Additionally, recent studies have focused on obtaining new products from quinoa grains, with greater added value, by isolating its chemical components such as protein, starch, oil, malt, dyes and saponin derivatives (Ballester-Sánchez, Gil, Fernández-Espinar, & Haros, 2019; Mufari, Miranda-Villa, & Calandri, 2018). Most of these studies involve wet-milling methods that allow the purest possible fraction of each component to be obtained. Although starch is the main product of wet-milling, there are other coproducts that could be used for technological and food purposes, such as the fiber-rich and protein-rich fractions (Ballester-Sánchez et al., 2019).

Although quinoa has been widely used as an ingredient (both as whole seed and as flour) in various foods, very few studies have examined its application in meat products, where it may be of technological interest. In this context, quinoa seeds have been used as fat replacers in beef burgers (Baioumy, Bobreneva, Tvorogova, & Shobanova, 2018) and in dry-cured sausages (Fernández-Diez et al., 2016), while quinoa flour has been used as extender or binder in beef meatballs (Bagdatli, 2018) and in cooked sausages (Hleap-Zapata & Rodríguez de la Pava, 2018).

However no studies have dealt with the addition of black quinoa grains to meat products, and therefore the aim of this work was to evaluate the effect of different strategies for using black quinoa (either as whole seeds or as a fiber-rich fraction of quinoa obtained from its wet-milling) as binder (replacing potato starch), in terms of their influence on nutritional composition and technological properties of bologna-type sausage.

2. Materials and methods

2.1. Plant materials

Black Bolivian Real seeds of quinoa (*Chenopodium quinoa Willd*) (BQ) obtained from organic farming were purchased from a local market. The fiber-rich fraction (FRF) was obtained as a coproduct from black quinoa wet-milling, according to the methodology developed by Ballester et al. (2019). The proximate composition of both ingredients was previously evaluated by Pellegrini, Lucas-González, Ricci, et al. (2018) [BQ: 5.27% moisture, 12.44% protein, 5.31% fat, 18.59% dietary fiber, 55.02% starch and 2.37% ash] and Roldán (2019) [FRF: 8.21% moisture, 15.92% protein, 3.29% fat, 38.30% dietary fiber, 27.72% starch and 3.13% ash].

2.2. Sausage manufacture

Bologna-type sausages were manufactured according to a traditional formula: 500 g/kg lean pork meat, and 500 g/kg pork backfat; Only meat ingredients add up to 100%, the amounts of the following non-meat ingredients are related to the total meat content: 150 g/kg water (in the form of ice), 30 g/kg potato starch, 25 g/kg sodium chloride, 300 mg/kg sodium tripolyphosphate, 500 mg/kg sodium ascorbate, 150 mg/kg sodium nitrite, spices (1 g/kg black pepper, 500 mg/kg nutmeg and 2 g/kg garlic powder). This original mixture was used as control sample (SC). The others two batches were obtained by replacing potato starch (30 g/kg) with black quinoa (SBQ) or with its fiber-rich fraction (SRFBQ) obtained as coproduct from the wet-milling of black quinoa. The high starch content in quinoa has allowed its application in the formula as binder replacer (substituting the potato starch that is usually used in these type of meat products).

The products were prepared in the pilot plant at Miguel Hernández University following normal industrial processing methods. Fresh lean pork meat (from shoulder) and backfat were obtained from a local market in different days. Lean pork meat and sodium chloride were chopped together in a cutter (R 2 Robot-Coupe, Robot-Coupe S.N.C., Vincennes Cedex, France) to enable the extraction of the salt soluble proteins. After that, the rest of ingredients and additives were added. Then, pork backfat was incorporated into approx. 4–5 cm^3 pieces and chopped again to obtain a homogenous meat batter. This batter was stuffed using 80 mm diameter water impermeable plastic casing (Fibran-Pack, Fibran, Girona, Spain). Sausages (300 g approx.) were cooked in a water bath until 72 °C was reached in the inner of the product. Then, they were cooled in a water bath and maintained at 4 °C until analysis. Processing was repeated three times with each formulation.

2.3. Proximate composition

The moisture, ash, protein, total dietary fiber and fat, content were determined by AOAC (2016) methods.

2.4. Technological properties

2.4.1. Emulsion stability

The procedure of Hughes, Cofrades, and Troy (1997) was followed to assess emulsion stability. Briefly, 10 g of raw meat batters were centrifuged and heated, removing the supernatant and weighing the pellet. The amount of total expressible fluid (TEF) was calculated as follows:

$$\%TEF = \frac{Weight\ \ centrifuge\ \ tube\ \ and\ \ sample - Weight\ \ centrifuge\ \ tube\ \ and\ \ pellet}{Weight\ \ sample} \times 100$$

2.4.2. pH and water activity

The pH of the sausages was measured directly using a Hach puncture electrode probe (5233) connected to a pH-meter (model SensION^{TM} + pH3, Hach-Lange S.L.U., Vésenaz, Switzerland). The measurement was taken three times, changing the place of electrode insertion.

The water activity (aw) was measured at 25 °C using an electric hygrometer NOVASINA TH200 (Novasina; Axair Ltd., Pfaeffikon, Switzerland).

2.4.3. Color

The color of the samples was measured using the CIELAB Color Space (AMSA, 2012). The following color coordinates were determined: lightness (L*), redness (a*, ± red-green), and yellowness (b*, ± yellow-blue). The chroma saturation index [$C^* = (a^{*2} + b^{*2})^{1/2}$], the hue angle ($H^* = \tan^{-1} b^*/a^*$), and the color differences [$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$] with respect to control sausage, were also estimated. The reflectance spectra at every 10 nm between 360 and 740 nm were also obtained. From these spectra, the percentages of the areas corresponding to each of the basic colors of white light (violet 400–450 nm, blue 450–520 nm, green 520–580 nm, yellow 580–600 nm, orange 600–650 nm and red 650–700 nm) with respect to the spectra total area, were calculated according to Newton-Cotes Rule (Clenshaw & Curtis, 1997). Color determinations were made at 12 ± 2 °C by means of a Minolta CM-700 (Minolta Camera Co., Osaka, Japan) spectrophotometer with illuminant D65, 10° observer, 11 mm aperture of the instrument for illumination and 8 mm for measurement. Following AMSA guidelines (AMSA, 2012), values were the average of 9 measurements from each sample.

2.4.4. Texture

The textural properties were evaluated using a Texture Analyser TA-XT2 (Stable Micro Systems, Surrey, England). Texture profile analysis

(TPA) was performed upon cubes of 1 × 1 × 1 cm, obtained from the central zone of each sausage, after removing their casings. The samples were compressed twice to 70% of their original height using a compression load of 25 kg and a cross-head speed for 20 cm/min. The texture profile was determined as described by Bourne (1978). All instrumental texture analyses were conducted on chilled (4 °C) samples.

2.4.5. Residual nitrite level

Residual nitrite level (mg $NaNO_2$/kg sample) was determined in agreement with ISO/DIS 2918 standards (ISO, 1975).

2.4.6. Lipid oxidation

Lipid oxidation was assessed in triplicate by the 2-thiobarbituric acid (TBA) method following the recommendations of Rosmini et al. (1996). TBARS values were calculated from a standard curve of malonaldehyde (MA) and expressed as mg MAD/kg sample.

2.5. Statistical analysis

Results are reported as average ± standard deviation. A completely randomized design was used for all the properties and the results were analyzed by using a one-way Analyses of Variance (ANOVA). A Tukey's post hoc test was used to determine differences between the mean values for the different treatments ($p < 0.05$). All these analysis were performed using IBM SPSS Statistics 23 (IBM, USA).

3. Results and discussions

3.1. Proximate composition

Table 1 shows the results for the proximate composition of the sausages. As regards the proximate composition, moisture, fat, TDF and ash contents showed differences ($p < 0.05$) between samples from the different treatments. No differences were observed in the protein content regardless of the formulation used (Table 1). The addition of 3% quinoa (in either of its presentations: seeds or fiber-rich fraction) decreased the moisture content ($p < 0.05$) and increased the TDF and fat contents ($p < 0.05$) in sausages. This increase in TDF and fat content was higher ($p < 0.05$) in SRFBQ than in SBQ samples. The results for the TDF content were to be expected because the fiber-rich fraction from quinoa has a higher TDF content than quinoa whole seeds. However, the differences in the fat content were less expected because quinoa whole seeds (BQ) have a higher fat content than their corresponding fiber-rich fraction (RFBQ) [5.31% BQ (Pellegrini, Lucas-González, Ricci, et al., 2018) and 3.29% RFBQ (Roldán, 2019)]. On the other hand, a significant increase in the ash content ($p < 0.05$) was observed only when quinoa was added as fiber-rich fraction (SRFBQ), which can be explained because most of the mineral content in quinoa seeds is located in the pericarp, associated with pectic compounds of the cell wall (Vega-Gálvez et al., 2010).

3.2. Technological properties

3.2.1. Emulsion stability

The percentage of total expressible fluid (TEF) reflects the mixture of water and fat separated from the supernatant, and is used as a measure of the possibility of exudates during sausage shelf-life. Therefore, higher TEF values mean lower emulsion stability. The addition of both quinoa seeds and its fiber-rich fraction decreased ($p < 0.05$) TEF values (Table 2), meaning that emulsion stability was positively affected. The technofunctional properties (the water and oil holding capacities and the swelling capacity) of both ingredients were previously determined (Fernández-López, Lucas-González, Roldán, et al., 2019) the fiber-rich fraction of black quinoa showing higher values ($p < 0.05$) than quinoa seeds (for all of these properties), so that this coproduct could be applied in different food matrices to enhance water or oil retention during mixing ingredients and to enhance their cohesion. In this sense, these properties could be responsible for the differences in TEF between SBQ and SRFBQ sausages.

3.2.2. pH and water activity

The pH of sausages was not modified by the addition of either form of black quinoa ($p > 0.05$; Table 2). All the sausages showed a similar pH value of < 6.50, which is typical in this type of cooked sausage.

The addition of 3% quinoa (as seeds or fiber-rich fraction) decreased ($p < 0.05$) the water activity values in sausages (Table 2), with no difference between them. This decrease could be due to the water holding capacity of both ingredients (related to their TDF content), which decrease water availability (Fernández-López, Lucas-González, Roldán, et al., 2019).

3.2.3. Color properties

The color of meat and meat products is the first characteristic that makes an impression on consumers and is one of the most intuitive factors influencing consumer purchase decisions (Font I Furnols & Guerrero, 2014). The color parameters of sausages are shown in Table 3. Lightness, yellowness and chroma were affected ($p < 0.05$) only when the fibre-rich fraction of black quinoa was added (SRFBQ), these samples showing the lowest values for all three parameters. Sausages with quinoa added as whole seed (SBQ) only differed from control samples in redness and hue ($p < 0.05$). The addition of black quinoa seeds decreased redness but increased h° values. Nevertheless, taking into consideration the differences in color between the sausages with added quinoa (SBQ or SRFBQ) with respect to the control samples, the only sample that clearly differed from the control was the SRFBQ sample. It should be remember here that only color differences higher than 3 units are detected by the human eye (Martínez, Melgosa, Pérez, Hita, & Negueruela, 2001).

For a deeper knowledge about the effect of an ingredient on the color modifications in a food to which it has been added, is interesting the study of the reflectance spectra of both the ingredients and final product. Fig. 1 presents the reflectance spectra (360–740 nm) obtained for the three sausages (SC, SBQ, SRFBQ) and also for both forms of quinoa used (BQ and RFBQ). The shape of the reflectance spectra of the three cooked sausages is typical of that reported for cooked-cured meat

Table 1
Proximate analysis (% on fresh matter) of bologna-type sausages.

	Moisture	Protein	Fat	TDF	Ash
SC	61.98 ± 0.10a	13.85 ± 0.25a	20.14 ± 0.28c	–	2.89 ± 0.03b
SBQ	58.21 ± 0.25b	13.66 ± 0.29a	22.17 ± 0.24b	0.55 ± 0.03b	2.91 ± 0.01b
SRFBQ	57.58 ± 0.02b	13.44 ± 0.15a	23.60 ± 0.53a	1.11 ± 0.18a	3.05 ± 0.11a

SC: control sausage; SBQ: sausage with 3% black quinoa seeds; SRFBQ: sausage with 3% rich-fiber fraction from the wet-milling of black quinoa seeds; TDF: total dietary fiber.
Means ± standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$).

Table 2
pH, water activity (Aw), emulsion stability (expressed as % of total expressible fluids (TEF)), residual nitrite level and lipid oxidation (TBARS values) of bologna-type sausages.

	pH	Aw	TEF (%)	Residual nitrite level (mg $NaNO_2$/Kg sample)	TBARS (mg MA/Kg sample)
SC	6.40 ± 0.01a	0.967 ± 0.001a	2.68 ± 0.13a	32.86 ± 1.86c	0.44 ± 0.03a
SBQ	6.44 ± 0.01a	0.958 ± 0.001b	2.48 ± 0.07b	36.20 ± 0.23b	0.22 ± 0.03c
SRFBQ	6.42 ± 0.01a	0.956 ± 0.002b	2.27 ± 0.11c	43.64 ± 0.21a	0.30 ± 0.02b

SC: control sausage; SBQ: sausage with 3% black quinoa seeds; SRFBQ: sausage with 3% rich-fiber fraction from the wet-milling of black quinoa seeds.
Means ± standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$).

products (AMSA, 2012). The reflectance spectra of SC and SBQ were similar, with no differences between them ($p < 0.05$). By contrast, the reflectance spectrum of SRFBQ was similar to the other two only up to 440 nm, above, which significant differences were found for the rest of the evaluated wavelengths. As regards the reflectance spectra of the quinoa products (BQ and RFBQ) their shape is completely different from that of the sausages and the reflectance spectrum of RFBQ showed higher ($p < 0.05$) percentages of reflectance than BQ for all the evaluated wavelengths. In view of these results it can be concluded that the addition of quinoa products (BQ and RFBQ) have no colorant effect on sausages, despite the fact that contain natural colorant (betalains) (Escribano et al., 2017). Several author have reported that the reflectance spectra in meat products with added natural colorants (e.g. paprika) take the shape of the added colorant reflectance spectrum, masking the typical shape of the meat product reflectance spectrum (Fernández-López, Pérez-Alvarez, Sayas, & López-Santoveña, 2002).

Fig. 2 shows the percentages of the areas corresponding to each of the basic colors of white light with respect to the total spectrum area, for the three sausages. The statistical analysis of these data revealed that there were not differences between SC and SBQ for any of the basic colors. In the case of the SRFBQ the differences were significant only for violet (higher values) and the red and orange (lower values) compared with the other two sausages. Gandía-Herrero and García-Carmona (2013) reported that violet betacyanins were one of the most relevant colorant compounds in colored quinoas. Taking into account that these compounds are mainly located in the seed coat, which is the principal component in the fiber-rich fraction, it was expected that sausages with this fraction added would show higher reflectance in the violet range.

3.2.4. *Texture analysis*

Table 4 shows the effect of quinoa on the textural properties of sausages. Of the four textural parameter analysed, only cohesiveness was slightly affected ($p < 0.05$) by the addition of quinoa (in either form), SBQ and SRFBQ samples being less cohesive than the control samples. During cooking, meat proteins are denatured and form a continuous cross-linked gel network, stabilized by a series of protein-protein interactions, hydrogen and disulfide bonds (Jiménez-Colmenero, Careche, & Carballo, 1994). In this case, the presence of quinoa could disrupt this gel network decreasing cohesiveness.

The addition of quinoa in the form of whole seeds, resulted in more gummy sausages ($p < 0.05$) than the control and SRFQB samples. Hardness and springiness were not modified ($p > 0.05$) by the addition of quinoa in either form.

3.2.5. *Residual nitrite level*

Nitrate/nitrite is used as curing agent in meat processing with important actions: fixes color, contributes to the cured meat flavor, helps in the inhibition of the growth of microorganisms, specifically *Clostridium botulinum*, and effectively controls rancidity by inhibiting lipid oxidation. In spite of this, the use of sodium nitrite for curing has not been without controversy, concerning the potential risk of the formation of carcinogenic, teratogenic, and mutagenic nitroso compounds which has led to a tendency toward decreased its application (Viuda-Martos et al., 2009). During processing, $NaNO_2$ undergoes reactions to produce NO, which coordinates with the ferroporphyrin of myoglobin to form bright-red $Mb(Fe^{2+})NO$ in acidic conditions. The outer protein of $Mb(Fe^{2+})NO$ is de-natured to generate reddish-pink nitrosohemochromogen during heating (Ning et al., 2019; Peg & Shahidi, 1996), which is responsible for the characteristic color of cooked nitrite-cured sausages. The residual nitrite levels of cooked sausages are shown in Table 2. As can be seen, the addition of black quinoa (both forms) increased ($p < 0.05$) residual nitrite levels, this increase being greater ($p < 0.05$) when the rich-fiber fraction of black quinoa was added. However, all these values were below that permitted in cooked meat products (100 mg/kg; EFSA, 2003). Several authors have reported that quinoa seeds are able to accumulate nitrate in their structure (Gutiérrez-Larrazabal et al., 2004), which could be responsible for the higher residual nitrite levels found in sausages with added quinoa. A similar effect has been reported in pâté (a cooked meat product) with quinoa flour added (Pellegrini, Lucas-González, Sayas, et al., 2018). These results are very interesting because the addition of quinoa to cured meat products could reduce (or even eliminate, depending on the concentration of quinoa added) the need to add nitrate/nitrite as curing agent which could be an interesting alternative for the development of ecologic cured meat products.

3.2.6. *Lipid oxidation*

The TBARS values are shown in Table 2. Control sausages showed the highest TBARs value ($p < 0.05$), while sausages containing quinoa (either form) showed lower values. The lowest TBARs value ($p < 0.05$) was observed when quinoa was added as whole seed. All samples showed TBARs values below 1.0 mg MDA/kg sample, which is considered the level of incipient rancidity (Ockerman, 1976). It is important to notice that control samples (without quinoa added), which had the lowest fat content showed the highest TBARs value, which suggest that quinoa has some compounds with an antioxidant capacity that helps to control lipid oxidation in cooked sausages. Several

Table 3
Color parameters [(L*) lightness, (a*) redness, (b*) yellowness, (C*) chroma or saturation index, (h*) hue and (ΔE*) color differences with respect to control sausage) of bologna-type sausages.

	L*	a*	b*	C*	h*	ΔE*
SC	64.10 ± 1.72a	6.02 ± 0.43a	10.12 ± 0.54a	11.78 ± 0.65a	59.29 ± 1.20c	
SBQ	64.25 ± 1.69a	4.96 ± 0.69b	10.22 ± 1.16a	11.38 ± 1.22a	64.10 ± 2.99b	1.07b
SRFBQ	58.86 ± 2.00b	3.08 ± 1.04c	7.14 ± 0.80b	7.81 ± 1.09b	67.11 ± 5.10a	6.71a

SC: control sausage; SBQ: sausage with 3% black quinoa seeds; SRFBQ: sausage with 3% rich-fiber fraction from the wet-milling of black quinoa seeds.
Means ± standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$).

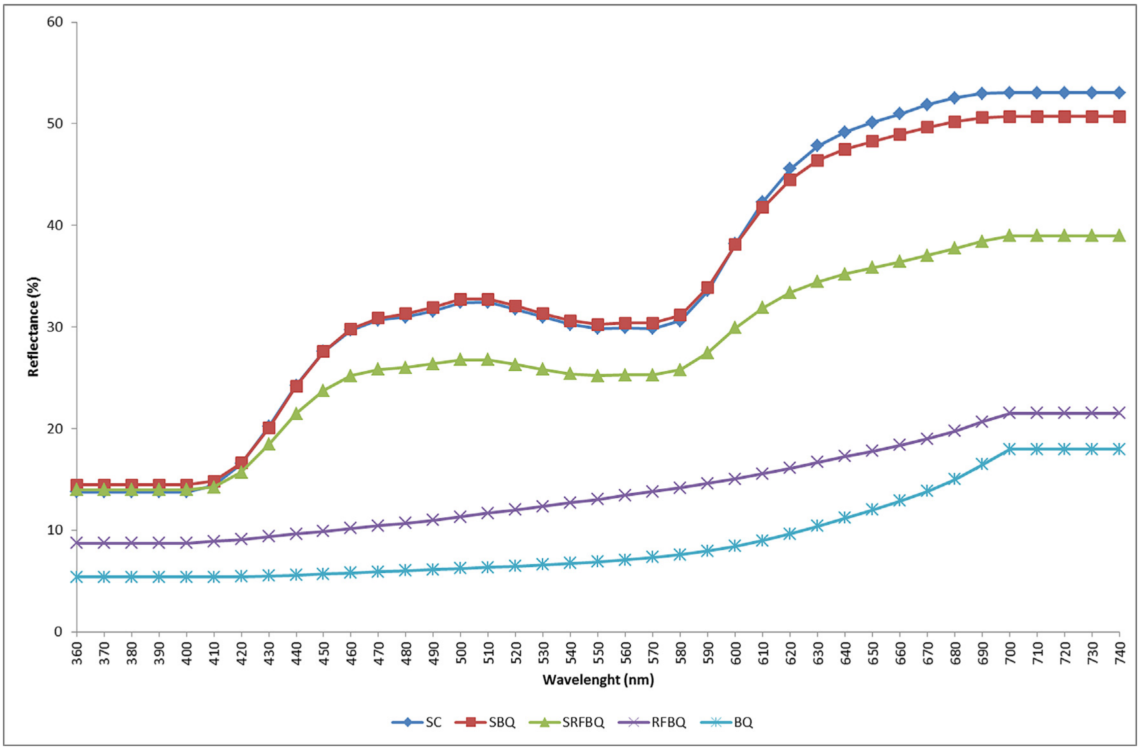

Fig. 1. Reflectance spectra (360–740 nm) of the functional ingredients [black quinoa seeds (BQ) and its fiber-rich fraction (RFBQ)] and the bologna-type sausages [control (SC), sausage with black quinoa seeds (SBQ) and sausage with its fiber-rich fraction (SRFBQ)].

components (flavonoids, phenolic acids and others) found in quinoa (at higher concentrations in colored quinoa seeds such as black quinoa) have been suggested as being responsible for their antioxidant characteristics which act mainly through their radical scavenging capacity and the reduction of lipid peroxidation (Pellegrini, Lucas-González, Ricci, et al., 2018; Tang et al., 2015).

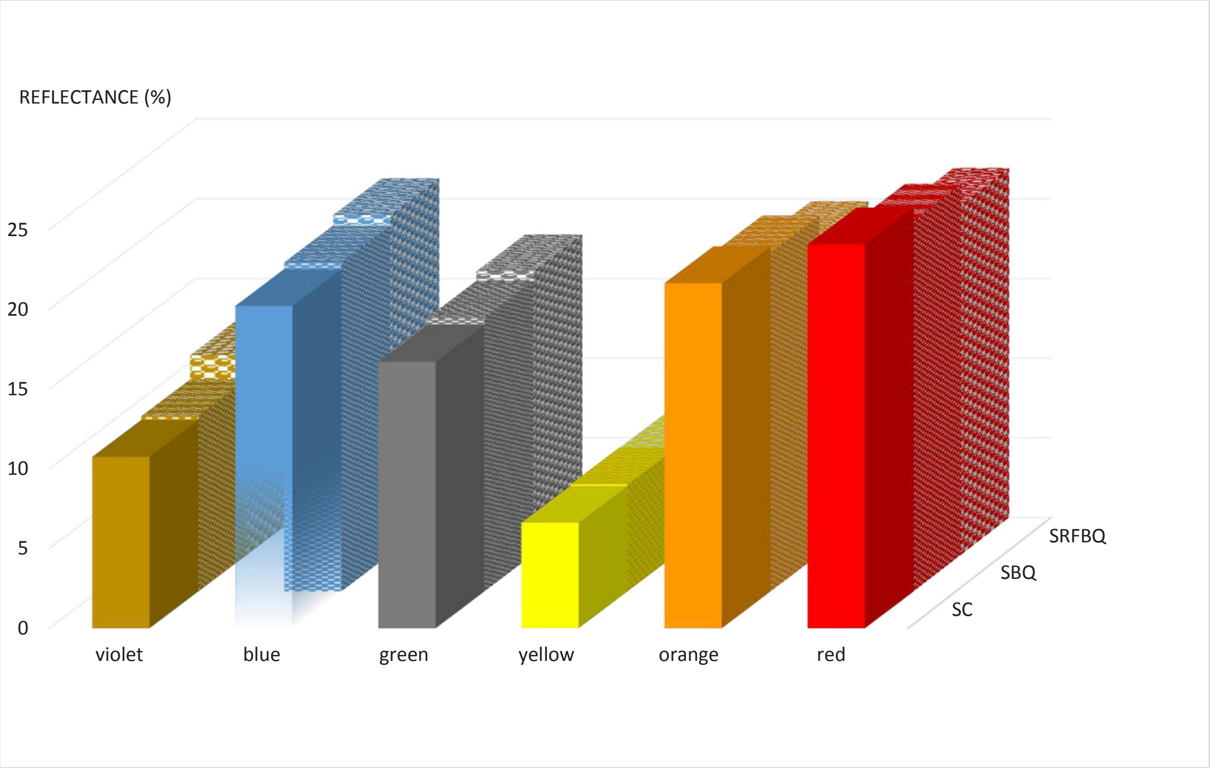

Fig. 2. Percentages of the reflectance spectrum areas corresponding to each of the basic colors of white light with respect to the total spectrum area, for control sausage (SC), sausage with black quinoa seeds (SBQ) and sausage with its fiber-rich fraction (SRFBQ).

Table 4
Texture Profile Analysis (TPA) parameters of bologna-type sausages.

	Hardness (N)	Cohesiveness	Springiness (mm)	Gumminess (N mm)
SC	6.62 ± 2.19a	0.87 ± 0.02a	0.81 ± 0.09a	5.71 ± 0.52b
SBQ	8.99 ± 0.76a	0.80 ± 0.01b	0.90 ± 0.01a	7.16 ± 0.84a
SRFBQ	7.14 ± 1.02a	0.81 ± 0.01b	0.85 ± 0.06a	5.78 ± 0.52b

SC: control sausage; SBQ: sausage with 3% black quinoa seeds; SRFBQ: sausage with 3% rich-fiber fraction from the wet-milling of black quinoa seeds.
Means ± standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$).

4. Conclusions

Quinoa seeds have attracted considerable scientific interest for use in human nutrition, not only for their consumption as whole grains but also as an ingredient in several food products for their possible technological interest. Reformulating bologna-type sausages with 3% black quinoa (either as whole seeds or as a fiber-rich fraction obtained from the quinoa wet-milling process) was seen to be a feasible strategy and may be a good choice not only for enhancing the nutritional composition of the sausages but also for its technological properties. In this respect, the most relevant effects on the technological properties of bologna-type sausages reformulated with black quinoa products (either form tested) were to enhance emulsion stability and to decrease lipid oxidation and water activity, properties with important implications for the stability of sausages during storage.

As regards color changes and residual nitrite levels, interesting results were obtained. Only the fiber-rich fraction of quinoa caused color differences, with respect to control sausages, that could be detected by the human eye. In addition, although the fiber–rich fraction did not modify the typical shape of the reflectance spectrum for cooked cured meat products, the reflectance percentages for several wavelengths were affected: higher values in the violet color range and lower values for red and orange. The addition of quinoa (in either form) resulted in higher residual nitrite levels (but still below that permitted in cooked meat products). This effect could be used for the development of natural cured meat products, avoiding the addition of nitrate/nitrite (depending on the amount of quinoa products added), without decreasing food safety.

CRediT authorship contribution statement

Juana Fernández-López: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Raquel Lucas-González:** Methodology, Investigation. **Manuel Viuda-Martos:** Conceptualization, Methodology, Visualization. **Estrella Sayas-Barberá:** Investigation, Visualization. **Jaime Ballester-Sánchez:** Resources. **Claudia M. Haros:** Resources, Funding acquisition. **Asunción Martínez-Mayoral:** Validation, Formal analysis. **José A. Pérez-Álvarez:** Conceptualization, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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