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Development of Functional Sausages: A Comparative Study of the Impact of Four Dietary Fibers on the Physico-Chemical Properties of Mortadella Sausages

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Background: The present study aimed to compare the impacts of incorporating four different dietary fibers, namely orange fiber (OF), wheat fiber (WF), bamboo fiber (BF), and carrot fiber (CF), on the physico-chemical properties of mortadella sausage.
Methods: The physical and chemical properties of the formulated mortadella sausages were assessed by measuring water activity (aw), pH, color, and thiobarbituric acid reactive substances (TBARs) parameters.
Results: The presence of fibers had negative effects on the aw measurements of the products, while pH values were less influenced. The analysis of color revealed that the treated sausages exhibited higher levels of lightness and yellowness, and lower levels of redness compared to the control group. Among the various fibers, OF made more changes than other fibers on product attributes at the end of the storage period with the following scores ($P \leq 0.05$): pH (6.22), a^* (4.84), b^* (13.68), L^* (67.76), whiteness Index (6.4.64), △E (6.24), and TBARs value (4.6 mg MDA/kg sample).
Conclusion: The lipid stability examinations revealed that while all of the fibers could hinder the progress of oxidation, OF was more efficient ($P < 0.05$). Based on the results, it can be concluded that OF has the suitable potential to be formulated in mortadella sausage.

1. Introduction

Despite the enormous nutritional benefits associated with the consumption of meat and processed meat products, such as beef, pork, veal, lamb, horse, and goat it is important to note that the International Agency for Research on Cancer has classified red meats as group 2A, probably carcinogenic to humans, while processed meats are classified as group 1, indicating that they are carcinogenic to humans (IARC, 2015). Other researchers have also shown the relationship between a lack of dietary fibers, particularly in meat products, and an increased risk of chronic diseases such as cardiovascular diseases and obesity (WHO/FAO, 2003). Dietary fibers can improve human health by reducing blood cholesterol levels and the risk of hypertension and hyperlipidemia, improving glucose tolerance, and contributing to gastrointestinal health (M. Viuda-Martos et al., 2010a). To ensure optimal digestion, a decreased risk of cardiovascular diseases, and a normal body weight, the World Health Organization (WHO), Food and Agriculture Organization (FAO), the European Food

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Safety Authority (EFSA), and most nutritionists recommend an average daily intake of 25 g of fiber for an adult (Ioniță-Mîndrican et al., 2022). The addition of dietary fibers to the formulation of processed meats has been proposed as a compensating approach to modify the nutritional quality of meat products (Aminzare et al., 2022; Verma & Banerjee, 2010). Currently, the incorporation of various types of dietary fibers such as apple, pea, sugar beet, citrus, and soy fibers into a range of food products is regularly fulfilled in the industry mainly due to their nutritional, technological, and functional properties (M. Viuda-Martos et al., 2010a). However, dietary fibers are most commonly incorporated into bakery goods compared to other food products, especially meat products. Furthermore, there is a lack of data comparing the addition of different dietary fibers in meat products, and it is challenging to make precise and citable comparisons across studies that investigate the application of various fibers in different foods. During our previous study, we assessed the effects of four dietary fibers, OF, WF, BF), and CF, on the sensory and microbiological characteristics of mortadella sausage (Aminzare et al., 2022). These fibers were selected according to their positive results reported in the literature (Grossi et al., 2011a; Ivanov et al., 2014; Mansour & Khalil, 1997; Manuel Viuda-Martos et al., 2010). They demonstrated acceptable functional properties in different meat products, such as bologna sausages, meat emulsions, and different types of sausages, while the overall physicochemical properties of the products were not negatively affected (Huang et al., 2011b; Magalhães et al., 2020; Pinton et al., 2022; Sayas-Barberá et al., 2012a). The present study aims to compare the effects of incorporating the aforementioned fibers on other important aspects of the shelf life of mortadella sausage, including lipid oxidation and physico-chemical properties such as pH, aw, and color changes in the product.

2. Materials and Methods

2.1 Materials

Pouya Faravaran Kamyab Co. (Isfahan, Iran) provided the studied fibers. The proximate compositions of the dietary fibers used in the study were explained in the previous work (Aminzare et al., 2022). All chemicals, reagents, and solvents used were of analytical grade.

2.2 Sausage production

To produce the sausages, a cooked emulsion-type sausage was prepared using chicken meat at a local plant (Dara Meat Products Factory, Shahriar County, Iran). The initial formulation consisted of the sausages included chicken meat (50 % w/w), water (ice, 18 % w/w), vegetable oil (16 % w/w), flour (10 %), potato starch (3 % w/w), sodium chloride (1.2 % w/w), garlic (0.7 %), spice mix (0.6 % containing black pepper, nutmeg, and ginger), sodium tripolyphosphate (0.5 %), sodium ascorbate (0.05 %), and sodium nitrate (0.012 %). The original formula was considered the control group, while the dietary fibers (OF, WF, BF, and CF) were added at the level of 1 % (w/w) to produce the actual treatments. The sausage preparation involved transferring frozen raw chicken meat and sodium chloride to a cutter to extract salt-soluble proteins. After comminution, the other additives and ingredients were added. Then, the fibers were added to the oil part and mixed. The resultant mixtures were stuffed into polyamide casings (150 mm long and 50 mm in diameter) using a vacuum filler (VF50, Handtmann, Germany), clipped, and cooked in a water bath. The cooking process lasted until the coldest point (the core of the sausage) reached 72 °C, as monitored using a thermocouple probe (Omega Engineering, CT, USA). Finally, the products were cooled to room temperature and kept under refrigeration conditions until analysis. The sausages were analyzed at 0, 10, 20, 40, and 60 days after production.

2.3 Physico-chemical examination

2.3.1 Color measurement

Color measurements were performed using a colorimeter (Minolta CR-210, Minolta Camera Co., Osaka, Japan; calibrated with a standard white plate, L* = +93.49, a* = –0.25, b* = -0.09) to determine the values of L* (lightness), a* (redness), and b* (yellowness) of each sausage at different sampling time. Equations (1) and (2) were used to compute the total color difference (△E) and whiteness index (WI) of the sausages, respectively.

$$\Delta E = [(L^*_t - L^*_0)^2 + (a^*_t - a^*_0)^2 + (b^*_t - b^*_0)^2]^{0.5} \quad \text{Eq. 1}$$

$$WI = 100 - [(100 - L^*)^2 + (a^*)^2 + (b^*)^2]^{0.5} \quad \text{Eq. 2}$$

where L^*_0, a^*_0, and b^*_0 are the color parameter values of the sausages on day 0 and L^*_t, a^*_t, and b^*_t are the color parameter values of the sausages in the other sampling times.

2.3.2 pH and aw determination

For the determination of pH values, 5 g of each sample was blended with deionized water (20 mL) for 2 min, and subsequently, a pH meter (Crison, Barcelona, Spain) calibrated with two buffers (pH 4.01 and pH 7.00 (BDH Laboratory Supplies)) was used for measuring the pH of the obtained suspensions. The aw of the sausage samples was determined using a Novasina TH-500 electrolytic hygrometer (Pfaeffikon, Switzerland) according to the manufacturer's instructions at 25 °C.

2.4 Lipid oxidation

Lipid oxidation was assessed by measuring the thiobarbituric acid-reactive substances (TBARs) values according to the method of Pikul et al. (1989) (Pikul et al., 1989). The TBARs values were calculated from a standard curve of malonaldehyde and expressed as mg MDA/kg sausage sample.

2.5 Statistical analysis

All examinations were performed in triplicate. SPSS software (version 16.0) was used for statistical analysis and all of the obtained data were analyzed statistically by one-way analysis of variance (ANOVA) and multiple comparisons were done by Tukey's tests. A significance level of $P \leq 0.05$ was considered statistically significant.

3. Results and Discussion

3.1 Physico-chemical analysis

3.1.1 pH and aw

Table 1 shows the pH values for the sausage samples formulated with various dietary fibers during 60 days of refrigeration. All of the values gradually declined over time, and this decrease was more significant since day 20 ($P < 0.05$). Despite some differences recorded between the treatments, these variations were not significant on the final day of storage ($P < 0.05$). However, there was a consistency between the pH of the sample with OF and the control.

Table 1. Changes in pH values of mortadella sausage containing different fiber types during refrigerated storage

Additive	Storage time (day)				
	0	10	20	40	60
Control	6.76 ± 0.01^{abC}	6.68 ± 0.02^{abC}	6.65 ± 0.02^{bC}	6.21 ± 0.04^{aB}	5.95 ± 0.07^{aA}
OF	6.72 ± 0.01^{aD}	6.55 ± 0.05^{aC}	6.51 ± 0.05^{aC}	6.13 ± 0.02^{aB}	5.89 ± 0.10^{aA}
WF	6.77 ± 0.01^{abC}	6.67 ± 0.03^{abC}	6.65 ± 0.01^{bC}	6.33± 0.05^{bBC}	6.11± 0.09^{aA}
BF	6.81 ± 0.02^{bD}	6.64 ± 0.07^{abC}	6.58 ± 0.02^{abC}	6.33 ± 0.03^{bB}	6.11 ± 0.04^{aA}
CF	6.74 ± 0.02^{aC}	6.69 ± 0.02^{bC}	6.61 ± 0.03^{bC}	6.24 ± 0.06^{abB}	5.91± 0.10^{aA}

* OF: Orange Fiber; WF: Wheat Fiber; BF: Bamboo Fiber; CF: Carrot Fiber.
* a-b The different lowercase letters in the same column indicate significant differences ($P < 0.05$).
* A-D The different uppercase letters in the same row indicate significant differences ($P < 0.05$).

The pH of a meat product is an important factor that affects the functional features and quality of the product during storage. A slight decrease in pH was repeatedly reported for different types of cooked sausages (Choi et al., 2013; M. Viuda-Martos et al., 2010b). This decline in pH is often attributed to the concurrent gradual growth of LAB and subsequent lactic acid production (M. Viuda-Martos et al., 2010a). It has been stated by several authors that the incorporation of different dietary fibers, such as citrus fiber into mortadella (M. Viuda-Martos et al., 2010a) and soy fiber into Bologna (Cofrades et al., 2000) had no significant effects on the ultimate pH of products. The cooking process can diminish the effects of fibers on the pH of cooked sausages by leaching out the fibers′ organic acids (Fernández-Ginés et al., 2004). Nevertheless, some reports indicated that formulated fibers can affect pH. For instance, Choi *et al.* (2008) reported that the addition of rice bran fiber enhanced the pH of frankfurters according to fiber alkalinity (Choi et al., 2008). Similarly, an increase in pH was reported in meatballs formulated with wheat bran (5, 10, 15, and 20 %) (Yılmaz, 2004). In the present study, on day 40, the pH of the WF sample was higher than the control group. The aw of the samples was measured on the first day of storage. The addition of the studied fibers into the sausage emulsion lowered the aw ($P < 0.05$). While the aw of the control sample was 0.98, the relevant values for the treated samples were between 0.95 and 0.96. Similar decreases in aw value were previously reported with the addition of 3.5 % wheat fiber in a Chinese-style sausage (Huang et al., 2011a) and 1 % orange dietary fiber in mortadella (M. Viuda-Martos et al., 2010a). The aw of a food product plays a crucial role in determining its rate of deterioration, and controlling aw is essential in the development of shelf-stable food items (Erkmen & Faruk Bozoglu, 2016).

Table 2. Changes in color scores of mortadella sausage containing different fiber types during refrigerated storage

Additive / Color parameter	Storage time (day)				
	0	10	20	40	60
*L**					
Control	66.45 ± 0.05^{aA}	66.47 ± 0.02^{aA}	66.52 ± 0.01^{aA}	66.92 ± 0.01^{aB}	67.08 ± 0.03^{abC}
OF	66.46 ± 0.04^{aA}	66.80 ± 0.03^{cB}	67.02 ± 0.06^{dC}	67.31 ± 0.07^{bD}	67.76 ± 0.09^{dE}
WF	66.44 ± 0.05^{aA}	66.68 ± 0.03^{bB}	66.86 ± 0.04^{cC}	66.96 ± 0.06^{aC}	67.24 ± 0.05^{bD}
BF	66.45 ± 0.02^{aA}	66.59 ± 0.04^{aB}	66.70 ± 0.02^{bC}	66.83 ± 0.06^{aD}	66.97 ± 0.04^{aE}
CF	66.50 ± 0.07^{aA}	66.70 ± 0.02^{bB}	66.80 ± 0.03^{bcB}	67.02 ± 0.06^{aC}	67.44 ± 0.10^{cD}
*a**					
Control	11.81 ± 0.04^{dE}	10.36 ± 0.10^{dD}	9.80 ± 0.08^{eC}	8.29 ± 0.04^{dB}	6.98 ± 0.11^{eA}
OF	10.61 ± 0.04^{bE}	9.14 ± 0.08^{aD}	8.07 ± 0.05^{aC}	6.50 ± 0.03^{aB}	4.84 ± 0.05^{aA}
WF	10.81 ± 0.03^{cE}	9.93 ± 0.04^{cD}	8.78 ± 0.09^{dC}	7.06 ± 0.06^{cB}	5.72 ± 0.06^{cA}
BF	10.60 ± 0.10^{bcE}	9.65 ± 0.08^{cD}	8.54 ± 0.06^{cC}	6.94 ± 0.07^{cB}	5.47 ± 0.09^{dA}
CF	10.41 ± 0.04^{aE}	9.38 ± 0.04^{bD}	8.29 ± 0.05^{bC}	6.74 ± 0.04^{bB}	5.10 ± 0.03^{bA}
*b**					
Control	9.89 ± 0.06^{aA}	10.01 ± 0.04^{aAB}	10.16 ± 0.04^{aB}	10.82 ± 0.04^{aC}	11.65 ± 0.10^{aD}
OF	11.71 ± 0.03^{cA}	12.32 ± 0.07^{cB}	12.30 ± 0.04^{cB}	12.87 ± 0.08^{dC}	13.68 ± 0.07^{dD}
WF	11.18 ± 0.08^{bA}	12.02 ± 0.07^{bB}	12.24 ± 0.08^{bcC}	12.43 ± 0.06^{bcD}	12.93 ± 0.06^{bE}
BF	11.26 ± 0.07^{bA}	11.92 ± 0.06^{bB}	12.08 ± 0.11^{bC}	12.39 ± 0.03^{bD}	12.91 ± 0.03^{bE}
CF	11.52 ± 0.11^{cA}	12.02 ± 0.03^{bB}	12.37 ± 0.04^{cC}	12.55 ± 0.05^{cD}	13.21 ± 0.07^{cE}

* OF: Orange Fiber; WF: Wheat Fiber; BF: Bamboo Fiber; CF: Carrot Fiber. Data are expressed as mean ± SD (n = 3).
* a-b The different lowercase letters in the same column indicate significant differences ($P < 0.05$).
* A-E The different uppercase letters in the same row indicate significant differences ($P < 0.05$).

3.1.2 Color properties

Color analysis of the treated sausages (Table 2) revealed that all three color parameters (lightness, redness, and yellowness) were significantly affected by the addition of fibers ($P < 0.05$). In this regard, L^* and b^* values increased with storage time in all samples, and the treated samples had higher values than the control. However, the a^* parameter decreased over time, with the control sample exhibiting the highest redness. Among the tested fibers, the mortadella sample formulated with wheat fiber was closer in color to the control sample. Several factors control the color quality of a meat product. The type of sausage, sausage components, type of manufacturing, length of storage, etc. The type of added fiber and its color quality have been frequently mentioned as factors affecting the color of meat products, particularly in the early stages after production (Cofrades et al., 2000; Fernandez-Gines et al., 2006; Sayas-Barberá et al., 2012b). For instance, the presence of yellow compounds (carotenes) and white components in citrus fiber was attributed to color changes ($b^*$and L^*) of *Longaniza de Pascua* and bologna respectively (Fernandez-Gines et al., 2006; Sayas-Barberá et al., 2012b). Sayas-Barberá *et al.* (2012) reported that the addition of OF increased yellowness (in the early days of storage), which was in agreement with our findings (the highest b* was recorded for the OF sample). The increase in L* and b* were also reported for pork sausages formulated with CF (Grossi et al., 2011b) and Chinese-style sausages incorporated with WF (Huang et al., 2011a). Fernandez-Gines *et al.* (2006) reported a negative and positive correlation between the moisture content and redness and lightness of bolognas formulated with different concentrations of lemon albedo (as a source of dietary fiber), respectively. They showed that the addition of the fiber source increased the moisture of sausages. This is in line with our findings, in which the presence of all four fibers resulted in lower b^* and higher L^* values in comparison with the control more likely due to the increase of moisture content. In fact, the lightness of meat products was mainly connected to the moisture of the products (Fernández-López et al., 2007). Despite the above reports, there are considerable studies showed that the addition of fibers of various origins could not induce changes in the color of the treated meat products (Hughes et al., 1997; Mansour & Khalil, 1997).

3.2 TBARs evaluation

In the present study, the ability of the added fibers to control the progress of oxidation in the mortadellas was assessed via the determination of TBARs. The initial TBARs values were 1.15-1.19 (mg MDA/kg sample) and reached a range of 4.64-4.89 (mg MDA/kg sample) on day 60 (table 3). Between days 10 and 20, the difference between the control and the actual treatments was significant, and the sausages containing the fibers exhibited lower oxidation ($P < 0.05$). In general, The TBARs values of the four formulated mortadellas were close to each other. However, the OF sample was the only sample that showed lower lipid oxidation during the late period of storage (days 40 and 60) compared to the control ($P < 0.05$).

Table 3. Changes in TBARS values (mg MDA/kg sample) of mortadella sausage containing different fiber types during refrigerated storage

Additive	Storage time (day)				
	0	10	20	40	60
Control	1.16 ± 0.04^{aA}	1.74 ± 0.07^{bB}	2.49 ± 0.05^{bC}	3.77 ± 0.07^{bD}	4.89 ± 0.14^{bE}
OF	1.16 ± 0.02^{aA}	1.59 ± 0.05^{abB}	2.06 ± 0.05^{aC}	3.52 ± 0.07^{aD}	4.64 ± 0.06^{aE}
WF	1.15 ± 0.04^{aA}	1.55 ± 0.02^{aB}	2.16 ± 0.06^{aC}	3.65 ± 0.02^{abD}	4.75 ± 0.05^{abE}
BF	1.19 ± 0.04^{aA}	1.53 ± 0.05^{aB}	2.13 ± 0.08^{aC}	3.64 ± 0.05^{abD}	4.78 ± 0.08^{abE}
CF	1.17 ± 0.03^{aA}	1.58 ± 0.07^{aB}	2.14 ± 0.06^{aC}	3.75 ± 0.06^{bD}	4.78 ± 0.05^{abE}

* OF: Orange Fiber; WF: Wheat Fiber; BF: Bamboo Fiber; CF: Carrot Fiber. Data are expressed as mean ± SD (n = 3).
* a-b The different lowercase letters in the same column indicate significant differences ($P < 0.05$).
* A-E The different uppercase letters in the same row indicate significant differences ($P < 0.05$).

Lipid oxidation is one of the major deteriorative causes limiting the quality and the shelf-life stability of various meat products. Although the main aim of considering dietary fibers as a part of the sausage formula is to promote the functionality of the product, the inhibitory effects of some of these materials on lipid oxidation were previously observed. For example, the addition of citrus fiber into bologna (1 or 2 %) (Fernandez-Gines et al., 2006) or mortadella (1 %) (M. Viuda-Martos et al., 2010a) significantly retarded the lipid oxidation in the products. Among different types of dietary fibers, the antioxidant impact of orange fiber was more reported. The bioactive compounds like polyphenols presented in the orange fiber were introduced as the probable cause of lower incidence of oxidation in the OF-formulated sausages (Fernandez-Gines et al., 2006; M. Viuda-Martos et al., 2010a). It seems that our observation related to the OF sample alongside the mentioned reports confirms the positive impact of OF on the shelf life of different sausages concerning its antioxidant properties. The mechanism of polyphenol antioxidant actions is related to their capacities to chelate metals, scavenge free radicals, donate hydrogen, and inhibit the enzymatic system responsible for starting oxidation reactions (Ehsani et al., 2019; M. Viuda-Martos et al., 2010b). Moreover, other dietary fibers obtained from different origins have shown antioxidant properties in various meat products. For example, oat flour in chicken kofta (Prasad et al., 2011), roasted flour in buffalo meat burger (Modi et al., 2004), and rice bran in frankfurter (Álvarez et al., 2011) could successfully hinder lipid oxidation. In this study and previous work, the OF incorporated samples represented greater shelf life compared to the other treatments. The nutritional and the impact of different products containing OF on food stability of various foodstuffs were previously demonstrated, and OF was introduced as a good fat replacer, prebiotic, and important antioxidant and antibacterial compound that could be used in different food formulas (Al-Dalali, 2019; de Moraes Crizel et al., 2013; Zhou et al., 2023).

4. Conclusion

In this paper, the incorporation of four dietary fibers was evaluated on the physico-chemical properties of mortadella sausages during 60 days. Based on the pH, aw, color, and oxidation analyses, the tested fibers had positive effects on the shelf life characteristics of the formulated sausages, which overall represented better quality compared to the fiber-free control samples during the storage. Indeed, these findings alongside the results of a previous study on the microbiological properties of fiber-incorporated sausages, highlight the potential of dietary fibers, such as OF, as a promising approach to enhance the shelf stability of mortadella sausage.

Authors' Contributions

Majid Aminzare: Study concept; data collection; funding acquisition; approval of the final version of the manuscript. Mohammad Hashemi: Study concept; designated the study; funding acquisition; approval of the final version of the manuscript. Asma Afshari: Study concept; data collection; approval of the final version of the manuscript. Seyyed Mohammad Ali Noori: Study concept; approval of the final version of the manuscript. Mohammadreza Rezaeigolestani: Study concept; manuscript writing; approval of the final version of the manuscript.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Ethical considerations

This study was approved by the Zanjan University of Medical Science, Zanjan, Iran (Code: IR.ZUMS.REC.1396.78).

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