Dietary fibre as phosphate replacement in all-beef model system emulsions with reduced content of sodium chloride

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Summary

The aim of this research was to examine the possibility of phosphate replacement in all-beef model system emulsions containing 0.3 % of phosphate (CON) with 0.3 % and 0.6 % of dietary fibre of various plant origin, namely, wheat (treatments WH3, WH6), maize (CN3, CN6), pea (PA3, PA6) and potato (PT3, PT6). The pH values of all treatments were similar (6.12–6.27) and corresponded to emulsified-type meat products. Phosphate replacement by fibre led to higher cooking loss (*CL*) values, from 1.29 (CN6) to 2.43 (PT6) times, not significantly only in CN6 and PA6. Increment in the fibre content led to a significantly lower *CL* only in the case of maize fibre. On the other hand, all treatments with dietary fibre had significantly lower fluid release under pressure compared to control, while the influence of different fibre types and increase in fibre content was not observed. WH6, CN3, CN6 and PA3 had significantly higher lightness, while all treatments, except for WH6 and PA6, had significantly higher redness. Yellow tones were similar within all treatments. Texture parameters were affected by phosphate replacement with dietary fibres, as hardness and chewiness were higher, while springiness and cohesiveness were lower. No effect of the type of fibre or its level was observed.

Keywords

meat emulsion; reduced salt; phosphate replacement; dietary fibre; emulsion stability; instrumental colour; instrumental texture

Meat products, such as frankfurters, mortadella or bologna, belong to the emulsion-type meat products, which are well known and readily consumed worldwide. These products are prepared by comminuting and mixing meat, fatty tissue, water or ice and various ingredients, among which salt, phosphates and nitrites are the most common. The protein/fat/moisture ratio and the content of used ingredients are of great importance for emulsion formulation and stability, water binding properties, processing yield, colour and textural properties, flavour and appearance, shelf life and safety of products.

Salt and phosphates are very important for emulsion formulation and stability because they promote solubilization of myofibrillar proteins and increase the swelling of fibres, thus influencing the processing yield, storage loss and texture properties of the product [1, 2]. Salt is also very important for flavour, shelf life and safety of meat products [3, 4]. In addition to exhibiting a synergistic effect with salt [1, 5], phosphates also exhibit other effects, such as binding metal ions, increasing pH or reducing raw batter viscosity [6], which are of great significance for technological properties of emulsified-type meat products. However, increased sodium intake has been linked to hypertension and kidney diseases [4], while acutely high phosphorus intake affects bone metabolism [7]. Furthermore, over the past several decades, there has been growing interest in products without negative effects on human health.

The commercial production of frankfurters without phosphates (and other ingredients with a similar effect) requires approximately 2.0–2.5 % of salt [3]. However, a reduction to approximately

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1.7 % in such products, without adverse effects, was reported [8]. The reduction to 1.2–1.3%, but with phosphates added, was successfully achieved in fat-reduced hot dog sausages [2]. Vasquez Mejia et al. [9] concluded that, in the presence of phosphates, salt levels of 1.3 % or higher were needed to obtain a stable meat emulsion. The literature data indicate that a reduction to the content below 1.5–1.7 % in emulsified-type sausages without phosphates added could significantly alter the technological and sensory properties and reduce shelf life. Exclusion of phosphates from meat batter, especially in salt- (and/or fat-) reduced ones, without at least substituting phosphates with an alternative ingredient to provide a similar functional effect, is not recommendable [10].

Dietary fibres exhibit several functional properties, such as gel-forming ability, water-binding capacity or oil-binding capacity [11, 12], which is why they can be used in meat emulsion preparation as potential (and most importantly "natural") alternatives to phosphates [10]. Dietary fibres were used in meat emulsions primarily in low-fat products [13–16], in products with improved fatty acid profile to enhance oil stability [17] or to enrich meat products with fibre [18]. However, recently there has been sporadic research into the use of fibre as a phosphate alternative [10, 19].

Regarding emulsion-type meat products formulation, backfat due to better technical properties compared to other fatty tissues (e.g. beef, mutton etc.) is the most common (and most studied as well) [20]. Regarding meat, because of the same reasons, beef is preferable to pork [21]. All-beef emulsions (beef and beef fat) are rarely studied compared to all-pork or beef-backfat ones. Moreover, usage of pork or backfat are restricted in some cultures.

The aim of this research was to evaluate the use of cereal (wheat and maize) and vegetable (pea and potato) dietary fibre as phosphate replacement in all-beef model system emulsions with reduced content of sodium chloride. The influence of this replacement was examined by evaluation of technological properties of all-beef emulsions, in particular of emulsion stability, instrumental colour and textural properties.

MATERIALS AND METHODS

Beef emulsion preparation

Nine different beef meat emulsions were prepared, namely, control (CON) and eight experimental ones. All were prepared from beef meat (round muscles with moisture of 74.8 ± 2.7 %, proteins content of 21.1 ± 0.8 % and fat content of 1.8 ± 0.3 %), beef fatty tissue and water in the ratio 40 : 25 : 35, with the addition of 1.5 % of nitric salt (with 0.6 % of sodium-nitrite) and 0.5 $g \cdot kg^{-1}$ of sodium isoascorbate. CON was prepared with 0.3 % of the polyphosphate commercial mixture (sodium tripolyphosphate and disodium pyrophosphate, P_2O_5 content approximately 60 %), which was replaced in modified treatments with four types of dietary fibre in the ratio 1 : 1 (0.3 % of fibre) and 1 : 2 (0.6 % fibre): maize – CN3 and CN6 treatments (ZTC 2000; ZTrim Corn, Mundelein, Illinois, USA; fibre content 88–92 %), wheat – WH3 and WH6 treatments (Sanacel Wheat 200; Milex, Rumenka, Serbia; fibre content ≥ 65 %), potato – PT3 and PT6 treatments (Potex; Milex; fibre content ≥ 65 %) and pea – PA3 and PA6 treatments (Milex; fibre content ≥ 55 %).

Beef and beef fatty tissue were bought at a local store in Serbia. The visible fat and connective tissue were trimmed off the meat. Then, the meat and fatty tissue were ground through an 8mm plate, weighed and put in thin layers at –20 °C for 2 h before use. Model system beef emulsions were prepared according to the following procedure. Ground and weighed beef and fatty tissue were put in a stainless steel container of a blender Waring 8011s (Waring, Torrington, Connecticut, USA), dietary fibre was added (for modified treatments) as well as cooled water (0–3 °C) with previously dissolved nitric salt, sodium isoascorbate (and phosphate mixture for CON), and stirred using a spoon. The mixture was then ground and emulsified for 15 s in a blender at speed 1, followed by 30 s at the highest speed. Each batter weighed 400 g. Batters with a temperature below 15 °C were taken for heat treatment.

Further procedure was carried out as described by Stajić et al. [22], specifically, approximately 50 g of each emulsion was stuffed in pre-weighed plastic tubes (volume 50 ml, diameter 27 mm), and then sealed and centrifuged at 3 000 ×*g* for 90 s (Centrifuge 5430R; Eppendorf, Hamburg, Germany) to eliminate air bubbles. The tubes were heated in a water bath at 80 °C until the temperature of 70 °C was reached in the centre (15 min), and then cooled and stored in the dark at 3 ± 1 °C overnight. Afterwards, all tubes were tempered at room temperature (22 ± 2 °C) for 1 h and the content was then taken out and wiped with paper towels. Two replications of the experiment were conducted on different days.

Methods

Four tube contents from each treatment were used for pH measurement, before heat treatments and after cooling the heat-treated emulsions, with pH-meter Testo 206 pH2 (Testo, Lenzkirich, Germany) equipped with a penetration probe. Before measurement, the pH-meter was calibrated with standard buffer solutions at pH 4 and pH 7.

Emulsion stability of model system emulsions was determined by cooking loss (*CL*), fluid release under pressure (*FRP*) and total fluid release (*TFR*).

CL (percentage of weight reduction) was calculated by the weight difference between four tube contents before and after heat treatment and cooling. Four samples (one cross-section per tube) were used for *FRP* (percentage of released liquid) determination as described by Stajić et al. [22]. *TFR* was calculated from *CL* and *FRL* using Eq. 1:

$$TFR = CL + \frac{(100 - CL) \times FRP}{100} \quad (1)$$

where *TFR, CL* and *FRP* were expressed in percentage.

Regarding the texture profile analysis, samples were taken from the centre of the cooked tube content, 10 mm in height and 15 mm in radius. Eight samples (two per tube) from each treatment were used and the further procedure was carried out as described by Stajić et al. [17]. The texture profile analysis was performed using the universal texture analyser TA.XT Plus (Stable Micro Systems, Godalming, United Kingdom). Samples were compressed twice to 50 % of their original height, with a compression aluminium platen of 25 mm (P/25) and a 50 kg load cell. Pre-test speed was 60 mm·min^{-1}, test speed was 60 mm·min^{-1} and post-test speed was 300 mm·min^{-1}. Hardness, adhesiveness, springiness, cohesiveness and chewiness were determined using the Exponent software (Stable Micro Systems, Godalming, United Kingdom).

Twelve samples (three cross-section samples per tube) were taken for instrumental colour measurements using the Computer Vision System (CVS) as described by Tomasevic et al. [23]. Sony Alpha DSLR-A200 digital camera (10.2 megapixel CCD sensor with DT-S 18–70 mm, F3.5–5.6 lens; Sony, Tokyo, Japan) was used. The standard 24-colour rendition chart X-Rite Colorchecker Passport (X-Rite, Grand Rapids, Michigan, USA) was used for camera calibration. The camera was connected to a Toshiba Portege R830 computer (Toshiba, Tokyo, Japan) equipped with a 2200 IPS LED external monitor (LG, Seoul, South Korea). The monitor with a sRGB gamut (standard RGB) was calibrated with X-Rite i1 Display Pro device (X-Rite) by selecting white chromaticity at 6500 K (illuminant D65), gamma at 2.2 and white luminance at 140 cd·m^{-2}. Software i1Profiler 1.5.6 (X-Rite) was used to create the ICC monitor profile. The Colorchecker and samples were photographed inside a cubical (a = 80 cm) wooden box with a removable top, inside coated with black opaque photographic cloth, equipped with four fluorescent lamps (60 cm long, 6500 K; Master Graphica TLD 965, Philips, Amsterdam, Netherlands) with designated light diffusers and located at a 45° angle and 50 cm above the samples. Using Photoshop CC software (Adobe, San Jose, California, USA), average colour sampler tool readings (L^*, a^*, and b^* values) were taken from photographs in raw format and 11 × 11 pixels measuring area. Chroma (C^*) was calculated according to Eq. 2:

$$C^* = \sqrt{{a^*}^2 + {b^*}^2} \quad (2)$$

Hue angle (h) was calculated according to Eq. 3:

$$h = \arctan\frac{b^*}{a^*} \quad (3)$$

Total colour difference (*TCD*) relative to CON was calculated according to Eq. 4:

$$TCD = \sqrt{\Delta {L^*}^2 + \Delta {a^*}^2 + \Delta {b^*}^2} \quad (4)$$

where

$$\Delta L^* = L^*_{\mathrm{MT}} - L^*_{\mathrm{CON}} \quad (5)$$

$$\Delta a^* = a^*_{\mathrm{MT}} - a^*_{\mathrm{CON}} \quad (6)$$

$$\Delta b^* = b^*_{\mathrm{MT}} - b^*_{\mathrm{CON}} \quad (7)$$

MT in subscript stands for modified treatments and CON in subscript stands for control treatment.

Statistical analysis

One-way ANOVA was performed to evaluate the effect of phosphate replacement with dietary fibre on technological properties of meat emulsions, using Statistica 12.5 software (StatSoft, Tulsa, Oklahoma, USA). Differences between means were determined using Tukey's HSD test at the significance level of $p < 0.05$.

RESULTS AND DISCUSSION

pH values before and after heat treatment

The pH values of raw batters with dietary fibre as a phosphate replacer were lower than those of CON by 0.09–0.15 pH units (Tab. 1). However, no significant differences were found ($p > 0.05$). Alkaline phosphates, which are mostly used in meat processing, increase the pH value of meat systems [24] but, due to the buffering capacity of meat, that

Tab. 1. pH values and emulsion stability of model meat emulsions.

Sample	pH*	pH	*CL* [%]	*FRP* [%]	*TFR* [%]
CON	5.92 ± 0.06	6.27 ± 0.01 ^{a}	5.4 ± 0.7 ^{f}	8.2 ± 0.9 ^{a}	13.2 ± 1.0 ^{bcd}
WH3	5.81 ± 0.07	6.20 ± 0.09 ^{ab}	9.7 ± 1.2 ^{bcde}	4.9 ± 0.8 ^{b}	14.2 ± 1.5 ^{abcd}
WH6	5.80 ± 0.08	6.15 ± 0.05 ^{ab}	10.1 ± 1.4 ^{bcd}	5.5 ± 0.6 ^{b}	13.9 ± 1.9 ^{bcd}
CN3	5.77 ± 0.08	6.12 ± 0.02 ^{b}	11.7 ± 1.0 ^{ab}	6.1 ± 0.9 ^{b}	17.0 ± 0.8 ^{a}
CN6	5.79 ± 0.09	6.17 ± 0.10 ^{ab}	7.0 ± 0.4 ^{ef}	4.6 ± 1.2 ^{b}	11.2 ± 0.9 ^{d}
PA3	5.81 ± 0.08	6.15 ± 0.03 ^{ab}	8.8 ± 1.4 ^{cde}	5.4 ± 0.9 ^{b}	12.7 ± 1.0 ^{cd}
PA6	5.83 ± 0.05	6.19 ± 0.05 ^{ab}	8.1 ± 1.1 ^{def}	5.1 ± 0.6 ^{b}	12.8 ± 1.0 ^{cd}
PT3	5.81 ± 0.07	6.17 ± 0.07 ^{ab}	11.3 ± 0.6 ^{abc}	4.9 ± 0.5 ^{b}	15.7 ± 0.3 ^{abc}
PT6	5.81 ± 0.10	6.14 ± 0.08 ^{ab}	13.1 ± 2.0 ^{a}	4.6 ± 0.4 ^{b}	15.9 ± 2.1 ^{ab}

Values (mean ± standard deviation) in the same column with different superscripts are significantly different ($p < 0.05$).
pH* – pH before heat treatment; *CL* – cooking loss; *FRP* – fluid release under pressure; *TFR* – total fluid release.
CON – emulsion with 0.3 % of polyphosphate; WH3, WH6 – emulsions with 0.3 % and 0.6 % of wheat fibre as phosphate replacer, respectively; CN3, CN6 – emulsions with 0.3 % and 0.6 % of maize fibre as phosphate replacer, respectively; PA3, PA6 – emulsions with 0.3 % and 0.6 % of pea fibre as phosphate replacer, respectively; PT3, PT6 – emulsions with 0.3 % and 0.6 % of potato fibre as phosphate replacer, respectively.

increase is in the range of 0.1–0.6 pH units [25]. After the heat treatment and 24 h of cooling, the pH values of all batters increased by 0.33 (PT6) – 0.39 (WH3) and were lower in all batters with dietary fibre by 0.07–0.15 units compared to CON. A significant difference ($p = 0.045$) was found only between CN3 and CON, while no significant differences within modified batters were found. The increase in the fibre content had no effect on the pH value of either raw or heat-treated batters. Magalhães et al. [19] also reported similar pH values of batters and bologna (with salt content of 1.5%) with 2.5% and 5% of bamboo fibre as phosphate replacer. By replacing phosphate with 0.5–1 % of citrus fibre, Powell et al. [10] also reported a decrease in pH, significantly only in batters with 0.5% of the fibre. The pH values of sausage batters with the added phosphate can increase by 0.0–0.4 pH units after heating [26]. In minced beef systems without phosphates and with 1.0–2.0 % of NaCl, Medyński et al. [27] found an increase of 0.31–0.33 in pH values after heating and 24 h of cooling, which was very similar to the findings in this study. The authors explained this effect by reduction of free acidic groups of proteins and by liberation of Ca^{2+} and Mg^{2+} cations. This indicates that phosphate replacement in meat emulsions did not alter the pattern of pH changes during heat treatment. All in all, the pH values were within the values reported for emulsified-type sausages made from beef [2, 4].

Emulsion stability

The phosphate replacement with dietary fibre significantly influenced the cooking loss (Tab. 1). All modified treatments had higher cooking loss, from 1.29 (CN6) to 2.43 (PT6) fold relative to CON, the difference being insignificant in CN6 and PA6. Increment in the fibre content led to a significantly lower *CL* only in the case of maize fibre (CN treatments). Powell et al. [10] also found an increase (up to 4 fold) of total fluid separation (after heat treatment and centrifugation) in batters with citrus fibre as a phosphate replacer, suggesting that increasing the fibre content to 0.75 % could reduce fluid separation, while higher contents had the opposite effect. In contrast, Magalhães et al. [19] reported significantly higher values (30–50 %) of released liquid in Bologna (pork and chicken) with 2.5 % of bamboo fibre as a phosphate replacement compared to treatments with phosphate and 1.5 % or 2.0 % of NaCl, whereas no differences were found when 5 % of bamboo fibre was used. Furthermore, in low-fat pork model system emulsions with reduced sodium content (to 1.5 %) and without phosphates, Han and Bertram [28] obtained significantly lower *CL* after adding 2 % of different fibre types (cellulose, carboxymethyl cellulose, chitosan and pectin).

In reduced-fat frankfurters (with regular phosphates and NaCl contents, together with a higher content of added water), Song et al. [15] reported significantly higher values of *CL* with the addition of 1 % of citrus fibre, but the addition of higher amounts of it (up to 3 %) led to a decrease in *CL* values, which were similar to control. The pH increase of 0.1–0.2 units in meat systems with pH above isoelectric point (*pI*) of muscle proteins (pH 5.0– 5.3), which is the case in this study, had small effects on the water holding capacity [29]. Thus, the higher *CL* in modified batters could be attributed to another functional effect of phosphates. During the comminution of meat (and fatty tissue) with the addition of water, salt and phosphate, insoluble myofibrillar proteins are solubilized. Phosphates promote this solubilization and exhibit a synergistic effect with salt, which also promotes protein solubilization. During heat treatments, solubilized myofibrillar proteins denature and coagulate, forming a gel (3D-network) with entrapped water and fat inside [25]. On the other hand, dietary fibre does not promote protein extraction and subsequent protein network formation during heat treatments, but rather binds, adsorbs and holds water [11]. Hence, higher *CL* in modified treatments could be the result of insufficient solubilization of myofibrillar proteins in the presence of low salt content and without phosphates.

The phosphate replacement with dietary fibres significantly reduced the amount of *FRP* (Tab. 1), with all treatments with dietary fibres having significantly lower *FRP* compared to CON. No influence of the fibre type or increase in their content in the initial batch was observed. The possible explanation could be related to the significantly higher *CL* values of modified treatments, as higher loss during heat treatment means lower retained free water that could be removed under pressure from the gel matrix. Bearing in mind that the same samples were compressed after heat treatment in order to gain comprehensive data on emulsion stability, *TFR* was calculated by combining the results of *CL* and *FRP*. The results of *TFR* were quite different, as modified treatments (except CN3) did not differ significantly from CON. Increased fibre level reduced *TFR* only in the case of maize fibre (CN treatments).

Instrumental colour

The colour of meat and meat products remains one of the most important quality attributes when it comes to the consumers and their preferences [30]. This is why the impact of dietary fibre on the colour of all-beef model system emulsions was of principal importance. We discovered that replacement of phosphate with dietary fibre increased lightness (Tab. 2). However, significant differences compared to CON were found only in WH6, CN3, CN6 and PA3. The increase in the fibre content led to significantly higher L^* values only in CN treatments. Except for the case of WH3, no significant differences were observed within modified treatments. Redness values were higher in all treatments with dietary fibre as a phosphate replacer, while the difference was insignificant in WH6 and PA6 compared to CON. It is possible that dietary fibres contain compounds with anitioxidant properties, such as tocopherols or phytosterols [31], which could promote nitrosyl myoglobin (NOMb) formation. Moreover, Powell et al. [10] pointed out that citrus fibre may also act as an antioxidant, although only when present on higher levels (1.5 %). The highest a^* values were determined when potato fibre was used as a phosphate replacement (PT treatments). In that case, significantly higher values were determined for PT6 compared to other "6" treatments, while no significant differences were found within "3" treatments. Similarly, PT treatments had the highest C^* values, the differences compared to CON being significant. No significant differences in parameters indicating yellow tones (b^* and h) were observed between CON and all modified treatments. Powell et al. [10] reported significantly higher b^* values, but no significant effect on L^*

Tab. 2. Instrumental colour properties of model meat emulsions.

	L^*	a^*	b^*	Chroma C^*	Hue angle h
CON	68.17 ± 1.88 ^{b}	8.78 ± 1.25 ^{e}	4.56 ± 0.77	9.90 ± 1.40 ^{d}	27.42 ± 2.63 ^{ab}
WH3	68.11 ± 2.53 ^{b}	10.61 ± 0.80 ^{abc}	5.58 ± 1.23	12.01 ± 1.25 ^{abc}	27.44 ± 3.65 ^{ab}
WH6	70.67 ± 2.60 ^{a}	9.39 ± 0.89 ^{de}	5.17 ± 0.85	10.72 ± 1.15 ^{cd}	28.67 ± 2.30 ^{a}
CN3	71.47 ± 1.67 ^{a}	10.61 ± 0.81 ^{abc}	4.81 ± 0.54	11.66 ± 0.80 ^{abcd}	24.40 ± 2.73 ^{b}
CN6	70.64 ± 1.51 ^{a}	10.22 ± 0.64 ^{bcd}	5.22 ± 0.84	11.51 ± 0.58 ^{abcd}	27.06 ± 4.39 ^{ab}
PA3	71.53 ± 2.25 ^{a}	10.06 ± 0.62 ^{bcd}	5.31 ± 1.02	11.39 ± 0.96 ^{abcd}	27.59 ± 3.52 ^{ab}
PA6	69.28 ± 1.73 ^{ab}	9.92 ± 1.17 ^{cde}	5.31 ± 0.82	11.26 ± 1.35 ^{bcd}	28.10 ± 2.35 ^{ab}
PT3	69.33 ± 1.01 ^{ab}	11.14 ± 0.81 ^{ab}	5.11 ± 0.66	12.27 ± 0.80 ^{ab}	24.67 ± 3.17 ^{ab}
PT6	69.33 ± 1.12 ^{ab}	11.47 ± 1.00 ^{a}	5.50 ± 0.76	12.74 ± 1.10 ^{a}	25.59 ± 2.68 ^{ab}

Values (mean ± standard deviation) in the same column with different superscripts are significantly different ($p < 0.05$).
CON – emulsion with 0.3 % of polyphosphate; WH3, WH6 – emulsions with 0.3 % and 0.6 % of wheat fibre as phosphate replacer, respectively; CN3, CN6 – emulsions with 0.3 % and 0.6 % of maize fibre as phosphate replacer, respectively; PA3, PA6 – emulsions with 0.3 % and 0.6 % of pea fibre as phosphate replacer, respectively; PT3, PT6 – emulsions with 0.3 % and 0.6 % of potato fibre as phosphate replacer, respectively.

and a^* values, of all-pork bologna sausage with various citrus fibre levels (0.5 %, 0.75 %, 1.0 %) as phosphate (0.5 %) replacers. Fernández-Ginés et al. [18] reported a progressive increment of L^*, a^*, b^*, C^* and h values of all-beef bologna sausage with the addition of 1–2 % of citrus fibre in the control formulation (regular salt and phosphate content). However, with the addition of the citrus fibre at a level of 0.5 %, a significant difference compared to CON was observed only in terms of L^*. Magalhães et al. [19] reported significantly higher L^* values when phosphate was replaced with bamboo fibre (2.5 % and 5 %) in pork and chicken bologna containing 1.5 % NaCl, which was lower compared to that with 2 % of NaCl, while a^* and b^* values were similar to bologna with 2 % NaCl, but with significantly higher a^* values and lower b^* values compared to that with 1.5 % of NaCl. Increase in the fibre content from 2.5 % to 5 % had no significant impact on colour properties. Increasing the fibre content led to lower *TCD* values (Fig. 1), except for the case of potato fibre (PT treatments). *TCD* values in all treatments (except for PA6) were higher than the level of 2.7, above which colour changes are noticeable by the human eye [32]. However, these values were in the range of 3–6 (from 2.8 in PT3 to 4.3 in WH3), which is taken as appreciable [32]. Results from Fig. 1 indicate that treatments with vegetable fibre (pea and potato) had lower *TCD* values (2.0–3.5) compared to those with cereal fibre (3.9–4.3).

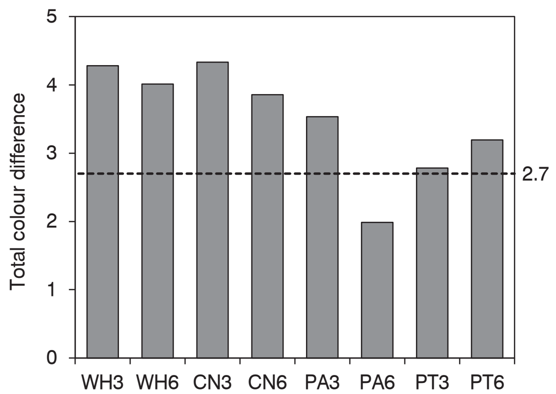

Fig. 1. Total colour difference of model meat emulsions compared to control.

Horizontal line indicates potential visual detection limit. Control – emulsion with 0.3 % of polyphosphate.
WH3, WH6 – emulsions with 0.3 % and 0.6 % of wheat fibre as phosphate replacer, respectively; CN3, CN6 – emulsions with 0.3 % and 0.6 % of maize fibre as phosphate replacer, respectively; PA3, PA6 – emulsions with 0.3 % and 0.6 % of pea fibre as phosphate replacer, respectively; PT3, PT6 – emulsions with 0.3 % and 0.6 % of potato fibre as phosphate replacer, respectively.

Instrumental texture

Texture parameters, except adhesiveness, were affected by the replacement of phosphates with dietary fibre (Tab. 3). However, no influence of the fibre type and its content was observed. Hardness was approximately 2 times higher (from 1.94 in PA3 to 2.24 in PT6, $p < 0.05$) in all modified treatments compared to CON. A similar ratio was observed in terms of chewiness, 1.77 (WH6) – 1.96 (PT3) times higher ($p < 0.05$) compared to CON.

Since phosphates and salt (NaCl) are very important in myofibrillar protein extraction being involved in protein-water, protein-fat and protein-protein interactions [2], their exclusion and/or reduction would probably impair the protein matrix formation and stability. Data indicate that insoluble fibre can alter food texture by forming a 3-dimensional network that can modify rheological properties [18] and increase hardness, as reported in several studies dealing with the addition of dietary fibre to emulsified-type meat systems with regular phosphates and/or salt contents. Moreover, higher cooking loss during heat treatment, equivalent to lower moisture content in final products, also leads to higher hardness [5]. Magalhães et al. [19] also reported significantly higher hardness and chewiness when replacing 0.5 % phosphate with 2.5 % or 5 % bamboo fibre in pork and chicken bologna, where higher amounts of fibre resulted in significantly higher hardness and chewiness. Higher values of hardness in low-fat emulsified-type meat products with regular phosphate and salt contents supplemented with 1–3 % citrus fibre were reported by Fernández-Ginés et al. [18] and Song et al. [15]. Han and Bertram [28] also reported higher values of hardness in pork model system emulsions with reduced sodium content (to 1.5 %) and without phosphates after adding 2 % cellulose and chitosan fibre. Moreover, Powell et al. [10], similarly to our study, also observed significantly higher hardness values in pork bologna sausage (with salt content reduced to 1.5 %) when replacing phosphates with 0.5–1 % citrus fibre and without significant differences between modified treatments. However, Powell et al. [10] did not report significant differences in chewiness. On the other hand, Song et al. [15] reported significantly higher values of chewiness, while Fernández-Ginés et al. [18] reported significantly lower values of chewiness compared to control.

Cohesiveness values were lower in all modified treatments compared to control, but the difference was significant only in PT6. According to available data, the addition of dietary fibre at less than 1.5 % (or even 2 %) to emulsified-type sausages

Tab. 3. Texture profile analysis results of model meat emulsions.

	Hardness [g]	Adhesiveness [g·s]	Springiness	Cohesiveness	Chewiness [g]
CON	578.82 ± 67.59 [b]	−9.52 ± 4.73	0.924 ± 0.026 [a]	0.689 ± 0.014 [a]	367.99 ± 39.35 [a]
WH3	1 267.99 ± 175.71 [a]	−9.67 ± 5.38	0.851 ± 0.054 [b]	0.665 ± 0.017 [ab]	715.86 ± 93.79 [b]
WH6	1 204.94 ± 183.78 [a]	−13.09 ± 7.07	0.832 ± 0.033 [b]	0.679 ± 0.011 [ab]	653.04 ± 72.53 [b]
CN3	1 245.31 ± 142.92 [a]	−15.42 ± 7.73	0.816 ± 0.044 [b]	0.678 ± 0.017 [ab]	687.78 ± 75.95 [b]
CN6	1 252.86 ± 185.83 [a]	−13.23 ± 7.76	0.831 ± 0.015 [b]	0.674 ± 0.017 [ab]	700.16 ± 94.73 [b]
PA3	1 172.53 ± 196.37 [a]	−8.81 ± 3.29	0.848 ± 0.038 [b]	0.680 ± 0.017 [ab]	672.33 ± 96.16 [b]
PA6	1 136.86 ± 110.82 [a]	−11.99 ± 6.14	0.848 ± 0.027 [b]	0.681 ± 0.016 [ab]	655.87 ± 63.11 [b]
PT3	1 281.77 ± 169.45 [a]	−10.70 ± 4.50	0.841 ± 0.044 [b]	0.668 ± 0.034 [ab]	724.01 ± 135.45 [b]
PT6	1 294.68 ± 202.26 [a]	−11.47 ± 6.91	0.818 ± 0.042 [b]	0.657 ± 0.016 [b]	692.10 ± 84.51 [b]

Values (mean ± standard deviation) in the same column with different superscripts are significantly different ($p < 0.05$).
CON – emulsion with 0.3 % of polyphosphate; WH3, WH6 – emulsions with 0.3 % and 0.6 % of wheat fibre as phosphate replacer, respectively; CN3, CN6 – emulsions with 0.3 % and 0.6 % of maize fibre as phosphate replacer, respectively; PA3, PA6 – emulsions with 0.3 % and 0.6 % of pea fibre as phosphate replacer, respectively; PT3, PT6 – emulsions with 0.3 % and 0.6 % of potato fibre as phosphate replacer, respectively.

with regular phosphates and salt contents, would most likely not lead to changes in cohesiveness. At adding up to 1.5 % of citrus fibre to the bologna sausage batter, Fernández-Ginés et al. [18] did not find any alteration of cohesiveness. In reduced-fat frankfurters, Song et al. [15] reported no significant influence of the addition of citrus fibre at a content of up to 2 %. However, Powell et al. [10] reported significantly lower cohesiveness in bologna sausage when replacing phosphates with 0.5 % and 1 % of citrus fibre, but not with 0.75 %. Moreover, Magalhães et al. [19] reported significantly lower cohesiveness values when replacing phosphates with 2.5 % and 5 % of bamboo fibre in pork and chicken bologna. Cohesiveness represents the strength of internal bonds in the gel matrix that is formed by extracted myofibrillar proteins during heating [5]. Since phosphates promote the extraction of myofibrillar proteins [5], insufficient amount of extracted proteins could impair matrix formation despite the presence of dietary fibre that can form a 3-dimensional network, which could lead to lower cohesiveness values even when a high content (e.g. 5 %) of the fibre was added.

Springiness was significantly lower in all modified treatments compared to CON, with no significant differences within them. Previous research data indicated that springiness was more affected by the addition of fibre than cohesiveness. Fernández-Ginés et al. [18] reported significantly lower springiness when adding 0.5 % citrus fibre (with regular salt and phosphates contents), without further changes when higher amounts were added (up to 2 %). However, in fat-reduced frankfurters (with regular salt and phosphates contents) Song et al. [15] reported lower springiness values, but without significant differences compared to control. Similar to this, lower values of springiness (without statistical significance) were reported in pork model system emulsions with a reduced sodium content (to 1.5 %) and without phosphates, after adding 2 % of various fibre types [28]. For bolognas containing 1.5 % salt with citrus fibre as a phosphate replacer, Powell et al. [10] determined lower springiness values compared to control, which were statistically significant only in sausages with 0.5 % fibre. Magalhães et al. [19] reported significantly lower springiness in pork and chicken bologna even when phosphates were replaced with a high amount (5 %) of bamboo fibre. A decrease in springiness in this study, and in others, could also be associated with an insufficient amount of extracted proteins since springiness represents the ability of the product to recover after deforming force is removed [33].

Song et al. [15] concluded that meat batters with citrus fibre had more compact, continuous structure, with a higher water-holding capacity. However, these batters had regular contents of phosphates and salt. Since NaCl exerts a stronger effect on the ionic strength and water-holding capacity, and phosphates had stronger effect on pH and protein solubility, not forgetting their synergetic effect [25], salt reduction and phosphate exclusion could affect the amount of extracted proteins and impair gel formation as well as its properties. Rodrigues et al. [2] determined lower values for hardness, chewiness and elasticity (springiness and cohesiveness) at reducing the salt content (in the range of 2–1 %) in fat-reduced hot dog sausages with a regular phosphate content and associated this to the emulsion stability, which was reduced by decreasing the salt content. This could be the reason for the higher CL and lower elasticity (springiness and cohesiveness) of treatments with fibre in this study.

CONCLUSIONS

Results of this study indicate that phosphate replacement with dietary fibre has a potential. Phosphate replacement with dietary fibre in all-beef model system emulsions did not alter the pH values, which were within the range suitable for emulsified-type sausages made from beef. Regarding emulsion stability, phosphate replacement with dietary fibre increased the cooking loss, except the treatments with 0.6 % maize and 0.6 % pea fibre. However, all treatments with dietary fibre had significantly lower values of fluid release under pressure, regardless of the type and amount of the added fibre. Therefore, compared to control, total fluid release values were significantly higher only in the treatment with 0.3 % of maize fibre. Usage of dietary fibre as phosphate replacers could increase the lightness and redness, while its influence on yellow tones was not significant. All treatments with dietary fibre as a phosphate replacer had significantly higher hardness and chewiness values, while springiness was significantly lower. The fibre type and amount had no further influence on texture parameters. The technological properties examined in this study are highly correlated with sensory properties (and thus to consumer acceptance) and they indicate good acceptance of potential products. Therefore, this could be a good step in developing innovative products. Further studies should focus on transferring this model system into a large-scale system and on further examination of the obtained products, which should include examination of microbiological and sensory quality in addition to technological properties.

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