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EFFECT OF VARIABLE CONTENT OF PHOSPHORUS AND COLLAGEN ON RHEOLOGICAL CHARACTERISTICS OF A MORTADELLA

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Abstract. The subject of the work was the assessment of the effect of variable content of total phosphorus and collagen in a model product on its rheological characteristics. The trial material was formed by 5 variants of model mortadella made of lean pork shoulder (40-60%), pork stomachs (10-30%), neck pork fat in cubes (20%) and 10% addition of water-fat-protein emulsion (5/5/1). The following factors were determined: water, total protein, fat, NaCl, total phosphorus and collagen contents. The so-called invariables were calculated, i.e. content ratios of: water to protein (Feder's number), fat to protein, phosphorus to protein and collagen to protein. The rheological properties of mortadella were tested with the CASRA method. The growing share of shoulder of higher protein content in the recipe resulted in an increase in total phosphorus content in the product and it led to strengthening of its structure and improvement of its consistency, which was shown in the linear increase in plasticity (*P*) and fall of product elasticity (*E*) and fluidity (*F*). The growing share of pork stomachs resulted in weakening of the structure and worsening of the product consistency, as shown by decrease in plasticity (*P*) and increase in elasticity (*E*) and fluidity (*F*).

Keywords: phosphorus, collagen, rheological characteristics, recipe meat products

INTRODUCTION

Phosphorus, found in muscle tissue, participates in the transformation of chemical energy into mechanical work, and the substances taking part in this change are the highly-energetic phosphorus compounds: adenosinetriphosphate (ATP), hydrolysis of which provides energy for contractions, and phosphocreatine (the store of energy for ATP regeneration). It is well known that the content of phosphorus naturally found in muscle tissue is positively correlated with protein content. Expressed in P_2O_5 it amounts to, depending on the protein content in the tissue, from 0.30% in bacon to 0.49% in sirloin muscles (Kłossowska 1998).

Apart from physiological phosphorus, in meat processing the phosphates added in the course of the technological process are applicable in order to increase juiciness and to improve water binding and consistency (Rutkowski and Gwiazda 1993, Tyszkiewicz and Tyszkiewicz 1972). The addition of biphosphates and polyphosphates in the amount of 1.6 g kg^{-1} resulted in achieving maximum rheological factors for sausages made of chicken meat (Zawadzka *et al.* 2003), and the research proved that the protein hydration rate influenced the plasticity (*P*) and elasticity (*E*), and the addition of polyphosphates influenced mostly the elasticity (*E*) and fluidity (*F*) (Tyszkiewicz 1989, Tyszkiewicz *et al.* 2006).

Collagen is one of the most important building substances for animal organisms and its quantity depends on the kind of tissue or organ, age, species, as well as sex (Bailey and Light 1989). While examining the influence of the basic chemical composition on rheological characteristics of the selected meat products, it was found that the collagen content in a product was very highly significantly correlated with the parameters of the CASRA method: negatively (adversely) with plasticity (*P*), positively with elasticity (*E*) and substantially positively – with fluidity (*F*) (Olkiewicz *et al.* 2007).

The aim of the work was the assessment of the effect of variable content of total phosphorus and collagen in a model product on its rheological characteristics.

RESEARCH MATERIAL AND METHODS

The trial material was formed by 5 variants of model mortadella made in the Semi-Technological Department of the Institute, prepared of lean pork shoulder (40-70%), pork stomachs (0-30%), neck pork fat in cubes (20%) and 10% addition of water-fat-protein emulsion (5/5/1), with the assumption of constant 70% aggregate content of shoulder and stomachs in the recipe. The variable percentage proportions of the shares of shoulder and stomachs were the raw material recipe modifying factors.

The percentage shares of the basic raw materials in the trial recipes are presented, among others, in Table 1. In Table 2, the basic chemical composition of the main components of the trial products raw material recipe is shown.

In all the trial variants the following set of additional raw materials and spices was applied: pickling mix (2.15%), saccharose (1.28%), sodium caseinate (1.00%) or defatted powdered milk (2.00%), polyphosphates (0.30%), sodium ascorbate (0.10%), monosodium glutamate (0.10%), black pepper (0.10%), white pepper (0.03%), garlic (0.02%), nutmeg (0.02%) and nutmeg flower (0.025%).

The well-chilled raw material (temp. +1 to –1°C) was ground in a meat grinder, successively with screens of mesh of ϕ20, ϕ10 and ϕ5, returning the ground raw material to the cold store after each grinding. On further chilling the ground raw material was cut in a cutter until the stuffing temperature of 15°C was reached. The stuffing was then filled into casings with ϕ100 and heated to the temperature of 72°C in the baton centre. Then the finished sausages were chilled to room temperature and placed in a cold store at temperature of about 4°C, from where they were taken for tests.

In the tested mortadellas the following factors were determined:

- water content (Wc) – with the dryer method according to PN-ISO 1442:2000,
- total protein content (Pc) – with the Kjeldahl method according to PN 75/ A-04018,
- fat content (Fc) – with the Soxhlet method according to PN-ISO 1444:2000,
- NaCl content (Nc) – with the potentiometric method according to PN-ISO 1841-2:2002,
- total phosphorus content (Ph) – with the method according to PN-A-82060:1999,
- collagen content (Cc) – with the method of determination of hydroxyproline according to PN-ISO 3496:2000.

For the tested products the following contents ratios were calculated: water to total protein (Wc/Pc – the Feder number being the measure of protein hydration), fat to protein (Fc/Pc), phosphorus to protein (Ph/Pc) and collagen to protein (Cc/Pc).

The rheological properties of the cured meat product block were tested with the Continuously Alternating Stress-Relaxation Analysis (CASRA) method, applying the UTM Zwick 1445 MOPS (Tyszkiewicz *et al.* 1997), determining the parameters as follows:

- plasticity (*P*) – parameter determining the force necessary to destroy the structure of the material of the tested object,
- elasticity (*E*) – parameter informing about reversible deformability of the shape of the tested object,
- fluidity (*F*) – parameter informing about irreversible deformability of the shape of the tested object.

In the tests, a bar of rectangular cross-section (2 x 20 mm) of the cross-section area $S = 4{,}0 \times 10^{-5}\ m^{-2}$ was applied, at the unit stress $\sigma_1 = 1{,}25 \times 10^4\ Nm^{-2}$.

The test results, constituting averages of three replications were subjected to analysis of linear regression, multiple regression and variance analysis, with the application of the statistical package Statgraphics for Windows ver. 3.

DISCUSSION OF RESULTS

In order to make possible simultaneous alteration of the percentage share of shoulder and percentage share of stomachs for each trial variant, the characteristic ratio (R) being the ratio of the percentage share of shoulder to the percentage share of stomachs in the raw material recipe was calculated (Tab. 1). To each value of the ratio of the percentage share of shoulder to the percentage share of stomachs in the raw material there corresponds only one average value of the Feder number (Fn – Wc/Pc ratio), resulting from the average basic composition of the tested products, which is presented in Figure 1. The relation between the (R) ratio and the Feder number is very highly significant (r= 0.98), and both factors may be applicable in exchange as independent variables of the tested relations.

Table 1. Main components recipe of model product, (R) – shoulder/porcine stomach ratio and Feder's number

Variant	Lean shoulder (%)	Porcine stomach (%)	Back fat cubes (%)	Fat-protein emulsion (%)	Sum of components (%)	Shoulder / porcine stomach ratio (R)	Feder's number (Fn)
W-1	40	30	20	10	100	1.33	3.79
W-2	45	25	20	10	100	1.80	3.55
W-3	50	20	20	10	100	2.50	3.39
W-4	55	15	20	10	100	3.67	3.22
W-5	60	10	20	10	100	6.00	3.10

Following the growing share of pork shoulder in the raw material recipe from 40% to 60%, in order to keep the aggregate 70% share of shoulder and stomachs, the share of pork stomachs decreased from 30% to 10% (Tab. 1) and the calculated (R) ratio increased from the value of 1.33 in the **W-1** sample (40% shoulder, 30% stomachs) to the value of 6.00 in the **W-5** sample (60% shoulder, 10% stomachs). Because, according to Table 2, the lean shoulder contains evidently much less water and more protein than stomachs, the increase in the share of pork shoulder in the recipe in result of the decrease in the protein hydration degree following the increase in protein content and decrease in water content in the pro-

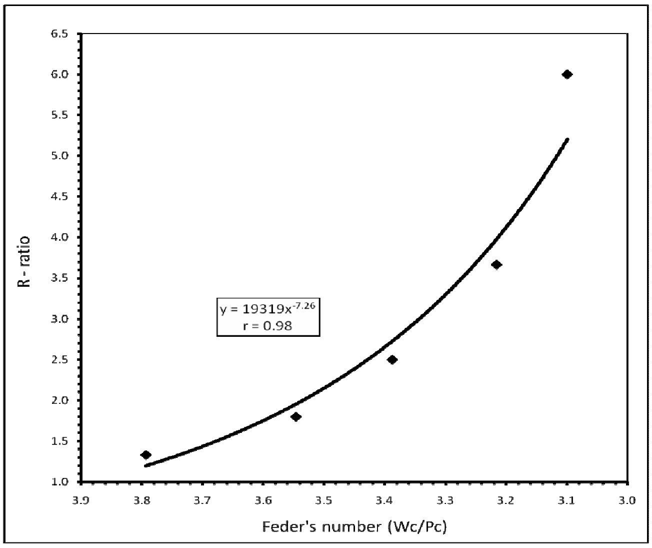

Fig. 1. Relationship between shoulder/porcine stomach ratio (R-ratio) and Feder's number

duct resulted in the decrease of the Feder number from the level of 3.79 to the level of 3.10. Thus, the results of previous tests were confirmed, showing that the modifications of the recipe composition, consisting in the change of raw materials of different content of water and protein, influence its hydration degree (Olkiewicz and Moch 2008).

Table 2. Chemical composition of main raw material for model sausage

Raw material	Water content (%)	Total protein content (%)	Fat content (%)	Collagen content (%)	Ash content (%)	Total phosphorus as P_2O_5 (g kg^{-1})
Porcine meat from shoulder	63.8	16.4	17.8	1.60	0.9	4.5
Porcine stomach	83.3	13.3	2.8	3.06	0.5	2.7
Back fat	9.0	3.9	87.6	3.65	0.1	–

The changes in the raw material recipe influenced, in a substantial way at least, the basic composition of the model products of the tested experimental variants (Tab. 3). The replacement of a part of pork stomachs with the equivalent quantity of pork shoulder in the raw material recipe, while keeping the aggregate share of these raw materials at the level of 70%, resulted in the decrease in water content in the product from 59.4% (**W-1** sample) to 55.5% (**W-5** sample) with simultaneous increase in total protein content from 15.7% (**W-1** sample) to 17.9% (**W-5** sample) at the level of content of NaCl in the product nearly unchanged (2.1-2.2%).

Table 3. One way Anova analysis of rheological and chemical characteristics

Variant	Rheological traits			Chemical traits					
Value	Plasticity (P)	Elasticity (E)	Fluidity (F)	Water cont. (Wc)	Total protein cont. (pc)	Fat cont. (Fc)	NaCl cont. (NC)	Phosphorus cont. (Ph)	Collagen cont. (Cc)
W-1	2.941 [a]	7.993 [c]	2.124 [c]	59.4 [e]	15.7 [a]	20.2 [a]	2.20 [bc]	4.61 [a]	1.83 [d]
W-2	3.149 [b]	7.804 [c]	2.040 [c]	58.6 [d]	16.5 [b]	20.2 [a]	2.22 [c]	4.68 [ab]	1.66 [c]
W-3	3.415 [c]	7.367 [b]	1.621 [b]	57.6 [c]	17.0 [c]	20.7 [ab]	2.23 [c]	4.74 [bc]	1.56 [b]
W-4	3.850 [d]	6.456 [a]	1.586 [ab]	56.3 [b]	17.5 [d]	21.3 [bc]	2.14 [ab]	4.76 [bc]	1.49 [a]
W-5	4.055 [e]	6.328 [a]	1.485 [a]	55.5 [a]	17.9 [e]	21.4 [c]	2.10 [a]	4.81 [c]	1.48 [a]
LSD	0,098	0,287	0,119	0.5	0.4	0.6	0,06	0.11	0.05

[a, b]means with different index in columns are significantly different ($P \leq 0.05$).

Following the increase in protein content and decrease in water content in the product, linear increase in total phosphorus content was noted, from the level of 4.61 g kg^{-1} (**W-1** sample) to the level of 4.81 g kg^{-1} (**W-5** sample), as well as linear decrease in collagen content from the level of 1.83% (**W-1** sample) to the level of 1.48% (**W-5** sample). The process of changes in the content of total phosphorus (Ph) and collagen (Cc) depending on the decreasing protein hydration degree (decreasing Feder number) is presented in Figure 2. In Figures 3-5, the relations between the phosphorus (Ph) and collagen (Cc) contents and other calculated invariables are presented, and namely: fat (Fc) to protein (Pc) contents ratio, phosphorus (Ph) to protein (Pc) contents ratio, as well as collagen (Cc) to protein (Pc) contents ratio. The collagen content was very highly significantly correlated to all the invariables. The phosphorus content, however, was highly significantly correlated to the following invariables: Wc/Pc, Ph/Pc i Cc/Pc. A lack of correlation of phosphorus content with the invariable Fc/Pc was noted (Tab. 4).

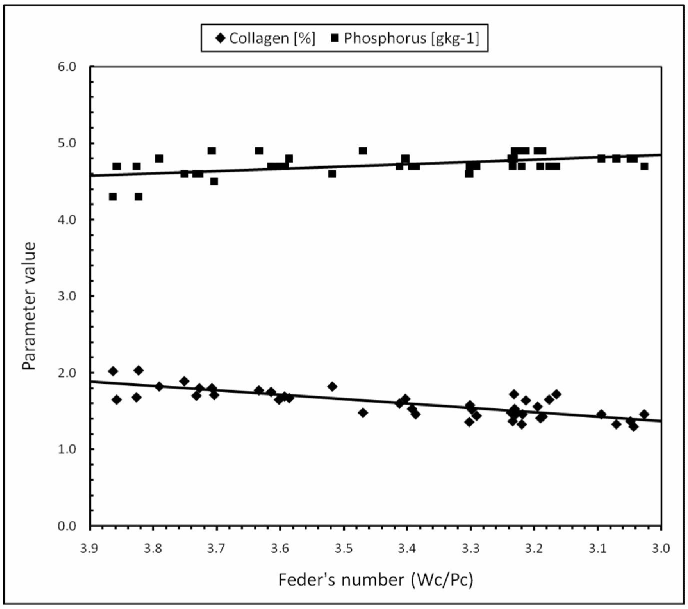

Fig. 2. Correlations between phosphorus and collagen contents and Feder's number (Wc/Pc)

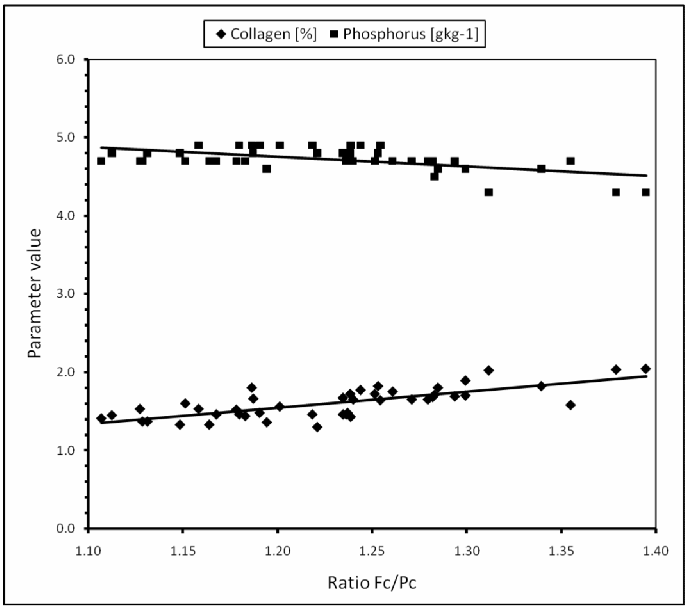

Fig. 3. Correlations between phosphorus and collagen contents and fat cont./protein cont. ratio (Fc/Pc)

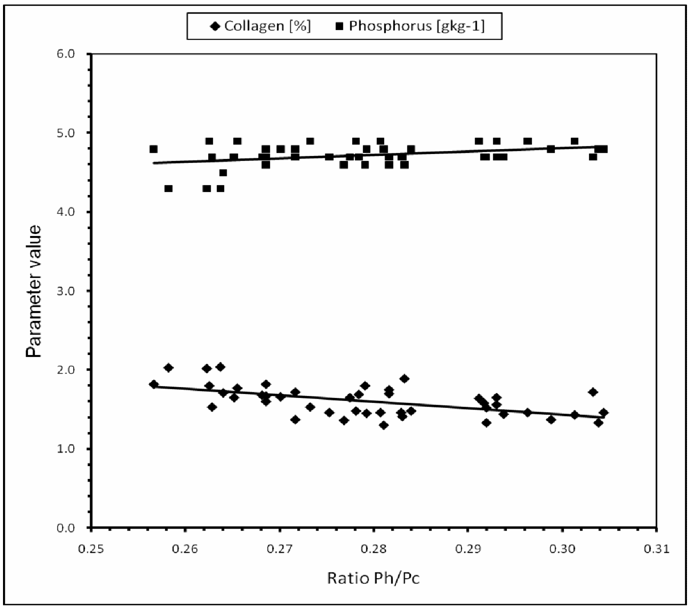

Fig. 4. Correlations between phosphorus and collagen contents and phosphorus cont./protein cont. ratio (Ph/Pc)

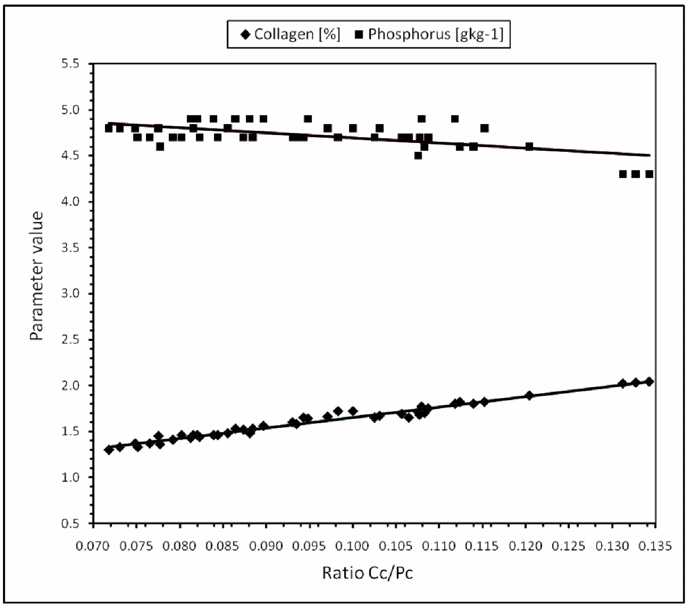

Fig. 5. Correlations between phosphorus and collagen contents and collagen cont./protein cont. ratio (Cc/Pc)

Table 4. Correlations between chemical and rheological variables of tested model products

Variable	Wc/Pc	Fc/Pc	Ph/Pc	Cc/Pc	*P*	*E*	*F*
Plasticity (*P*)	–0.90 ***	–0.46 **	–0.61 ***	–0.77 ***	–		
Elasticity (*E*)	0.83 ***	0.39 **	0.55 ***	0.70 ***	–0.96 ***	–	
Fluidity (*F*)	0.85 ***	0.48 ***	0.52 ***	0.74 ***	–0.85 ***	0.82 ***	–
NaCl cont. NC)	0.52 ***	0.38 **	0.52 ***	0.58 ***	–0.51 ***	0.52 ***	0.34 *
Phosphorus cont. (Ph)	–0.46 **	–0.24 ns	0.42 **	–0.40 **	0.51 ***	–0.50 ***	–0.50 ***
Collagen cont. (Cc)	0.81 ***	0.75 ***	0.60 ***	0.96 ***	–0.69 ***	0.62 ***	0.67 ***

Significance level: *** = P≤ 0.001, ** = P≤ 0.01, * = P≤ 0.05, ns not significant, Wc/Pc – water cont./protein cont., Fc/Pc – fat cont./ protein cont., Ph/Pc – phosphorus cont./ protein cont., Cc/Pc – collagen cont./ protein cont., *P* – plasticity, *E* – elasticity, *F* – fluidity.

From the data presented in Table 4 it results that the rheological parameters were, at least, highly significantly correlated to the calculated "invariables" characteristic for the tested products – plasticity (P) – negatively and elasticity (E) and fluidity (F) – positively. The content of NaCl in the product was very highly significantly correlated negatively to plasticity (–0.51***) and positively to elasticity (0.52***), as well as significantly positively correlated to fluidity (0.34*).

Special attention should be paid to the highly significant correlation of phosphorus and collagen contents with the parameters of the CASRA method due to the fact that in the trial conditions contradictory effects of these structure-creative factors to the product consistency and texture were noted (Tab. 4). The growing content of phosphorus in the product, at constant technological level of additions of polyphosphates at the level of 0.30%, resulting directly from the increase in protein content in the product, resulted in an improvement of consistency (Fig. 6), manifested in increase in plasticity (0.51***) and decrease in elasticity (–0.50***) and fluidity (–0.50***). Such a situation occurred with the replacement of a part of pork stomachs with lean shoulder in the raw material recipe. And the increase in collagen content in the product, resulting from the replacement of a part of lean shoulder with pork stomachs in the raw material recipe, was not able to compensate for the simultaneous substantial increase in water content in the product. That is why the aggregate effect of the action: positive increase in collagen content (+) and stronger negative increase of water content (--) resulted, in worsening of the product consistency (Fig. 7). In the products in which lean shoulder was replaced with pork stomachs, the texture was weakened, as confirmed by the decrease in plasticity (–0.69***) and increase in elasticity (0.62***) and fluidity (0.67***).

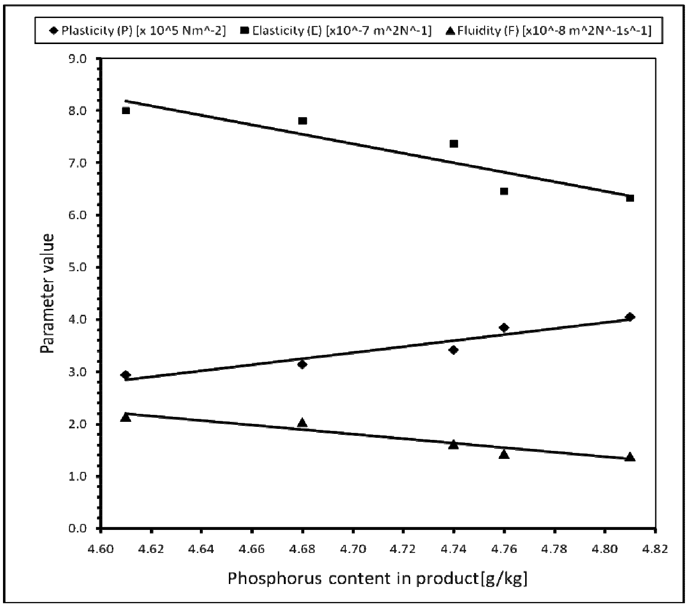

Fig. 6. Relationship between rheological characteristics (*P, E, F*) and phosphorus content in model product

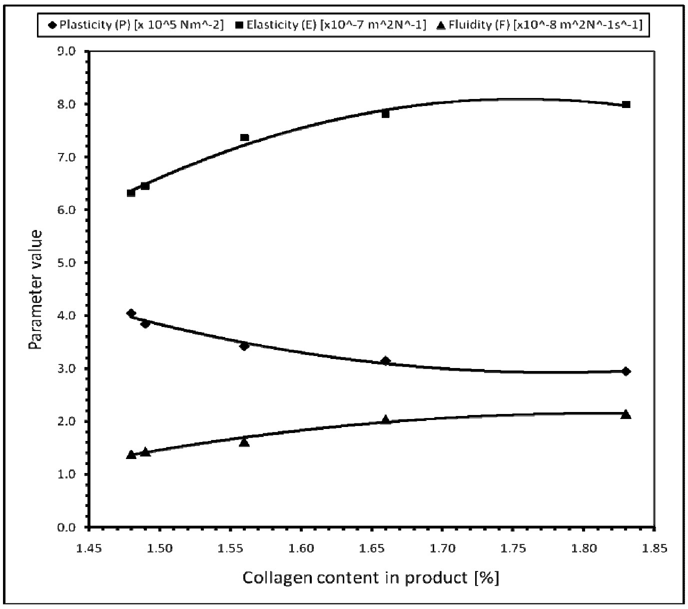

Fig. 7. Relationship between rheological characteristics (*P, E, F)* and collagen content in model product

The reason for the weakening of the consistency of the products of high share of pork stomach in the raw material recipe, in spite of the really high content of collagen and – on the contrary – of the strengthening of the consistency of the products of high share of lean shoulder, is easy to explain and it results directly from the basic composition of these raw materials. Pork stomachs are characterised by relatively low water content and lower content of total protein, as compared to lean pork shoulder which is characterised by relatively low water content and high total protein content (see Table 2). The above results confirm that the rheological characteristics of products depends, to a substantial extent, on the basic composition of the finished product (Tyszkiewicz *et al.* 2006, Olkiewicz *et al.* 2007, Olkiewicz, Moch 2008).

Table 5. Parameters of Multiple Regression Analysis for rheological traits

Parameters	Multiple regression $Y_i = C + aX_1 + bX_2 + cX_3 + dX_4 + eX_5$	Correlation coefficient
Plasticity (P) (x 10^5 Nm^{-2})	P = 5.30 – 1.32(Wc/Pc) + 0.07(Fc) – 0.48(Nc) + 0.40(Ph) + 0.29(Cc)	r = 0.91 ***
Elasticity (P) (x 10^{-7} m^2N^{-1})	E = 5.38 + 1.97(Wc/Pc) – 0.14(Fc) +1.33(Nc) - 0.81(Ph) – 0.62(Cc)	r = 0.86 ***
Fluidity (F) (x 10^{-8} $m^2N^{-1}s^{-1}$)	F = 1.68 + 0.87(Wc/Pc) – 0.03(Fc) - 0.40(Nc) – 0.30(Ph) – 0.02(Cc)	r = 0.71 ***
Plasticity (P) (x 10^5 Nm^{-2})	P = 2.79 + 0.59(Ph) – 1.32(Cc)	r = 0.71***
Elasticity (P) [(x 10^{-7} m^2N^{-1})	E = 8.61 – 0.99(Ph) + 2.03(Cc)	r = 0.65***
Fluidity (F) (x 10^{-8} $m^2N^{-1}s^{-1}$)	F = 2.93 – 0.52(Ph) + 2.03(Cc)	r = 0.71***

Significance level: *** = P≤ 0.001, ** = P≤ 0.01, * = P≤ 0.05, ns not significant,
X_1 = Feder's number (Wc/Pc), X_2 = fat content (Fc), X_3 = NaCl content (Nc),
X_4 = phosphorus content (Ph), X_5 = collagen content (Cc).

In the Table 5 the results of multiple regression analysis of the rheological parameters of the tested products are presented. From the data presented in the upper part of the table it results that the rheological parameters are correlated, in a very highly significant way, to the main chemical features of the basic chemical composition: Feder number (X_1) characterising the dependence between protein and water contents (protein hydration degree) and fat content (X_2), NaCl (X_3), phosphorus (X_4) and collagen (X_5). In the lower part of the table the dependence of these parameters on phosphorus (X_4) and collagen (X_5) contents only is presented. These correlations are also very highly significant. From the presented equations it results that in the test conditions, following the increase in phosphorus content in the product (mark +) and decrease in collagen content (mark –), the plasticity (*P*) of the product was growing, testifying to the improvement of consistency. For elasticity (*E*) and fluidity (*F*) the effect is opposite. The said parameters were growing in the case of lowering the phosphorus content (mark –) and increasing the collagen content in the product (mark +), which testified to worsening of the product consistency.

CONCLUSIONS

1. It was shown that there exist, usually very highly significant, mutual correlations between the tested chemical and rheological factors and the calculated invariables.
2. The variable contents of total phosphorus and collagen affected the rheological parameters of model products in a very highly significant way.
3. Increase in the content of total phosphorus in the product strengthened its structure and improved its consistency, which was visible in the linear increase in plasticity (*P*) and decrease in elasticity (*E*) and fluidity (*F*).
4. In the test conditions the increase in collagen content in the product resulted in weakening of its structure and worsening of its consistency, which was visible in the decrease in plasticity (*P*) and increase in elasticity (*E*) and fluidity (*F*).

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WPŁYW ZMIENNEJ ZAWARTOŚCI FOSFORU I KOLAGENU NA CHARAKTERYSTYKĘ REOLOGICZNĄ MORTADELI

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S t r e s z c z e n i e. Przedmiotem opracowania była ocena wpływu zawartości fosforu ogólnego i kolagenu w modelowym produkcie na jego charakterystykę reologiczną. Materiał badawczy stanowiło 5 wariantów modelowej mortadeli wyprodukowanej z chudej łopatki wieprzowej (40-60%), żołądków wieprzowych (10-30%), słoniny karkowej (20%) oraz 10% dodatku emulsji wodno-tłuszczowo-białkowej (5/5/1. Oznaczano: zawartość wody, białka ogólnego, tłuszczu, NaCl, fosforu całkowitego oraz kolagenu. Wyliczano tak zwane niezmienniki to jest stosunki zawartości: wody do białka (liczba Federa W/B), tłuszczu do białka, fosforu do białka oraz kolagenu do białka. Właściwości reologiczne mortadeli badano metodą CASRA. Rosnący w recepturze udział łopatki o wyższej zawartości białka powodował wzrost zawartości fosforu ogólnego w produkcie i prowadził do wzmacniania jego struktury i poprawy konsystencji, co objawiało się liniowym wzrostem plastyczności (*P*) oraz spadkiem elastyczności (*E*) i płynności (*F*) produktu. Natomiast rosnący w recepturze udział żołądków wieprzowych o wyższej zawartości wody skutkował nieoczekiwanym osłabianiem struktury i pogarszaniem się konsystencji produktu, czego wyrazem były: spadek plastyczności (*P*) oraz wzrost elastyczności (*E*) i płynności (*F*).

S ł o w a k l u c z o w e: fosfor, kolagen, charakterystyka reologiczna, receptura surowcowa produktów mięsnych