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EFFECT OF BASIC CHEMICAL COMPOSITION AND FUNCTIONAL ADDITIVES ON RHEOLOGICAL CHARACTERISTICS OF SELECTED MEAT PRODUCTS

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A b s t r a c t. A study of selected popular market meat products was undertaken. The aim of the study was to examine their quality in a comprehensive way. The present work was undertaken in order to relate the rheological parameters of the employed methods (TPA, CASRA) with the level of functional components contained in the tested meat products, and to determine their effect on the rheological parameters. The following tests were carried out: basic chemical composition, Feder number, and the rheological test. The tested meat products revealed a high variability of the studied chemical discriminants and rheological parameters, which results from differentiated raw material composition, degree of protein hydration, and level of functional additives. The correlation analysis of rheological parameters of the studied products showed that the Feder number was best correlated with the rheological parameters. Multiple regression analysis allowed developing the equations of multiple regressions with the main chemical discriminants of the studied products for all the examined rheological parameters. The correlations indicated above and interactions between the studied rheological parameters and functional components of the tested products were well shown on PCA "bi-plots" and connect the relation between chemical composition of the product with the parameters of rheological characteristics.

K e y w o r d s: meat products, raw material composition, functional additives, rheology characteristics, Principal Component Analysis (PCA)

INTRODUCTION

We are encountered with a big variety of functional additives, appearing on the market, which may be employed in meat processing. They play many technological functions. They include, *inter alias*: preservatives, antioxidants, emulsifiers, emulsifying salts, acids and acidity regulators, colours, stabilisers, thickeners, gelling agents, flavour enhancers and modified starch. The legal status of food additives application is regulated by the Regulation of the Minister of Health of 23rd April, 2004 on admitted food additives and processing aids (Regulation 2004).

Such a situation allows the process engineers to introduce many new functional substances to the products as well as to employ those which are already in use but at new, increased rates, being limited only by the regulation mentioned above. The criterion of price which is often imposed on the producers during development of a product by big trade organizations, with distinctly increased possibilities of employing the functional additives, causes that a part of raw material of higher quality becomes replaced by a cheaper worse-quality raw material. Common use of cheaper fat and collagen substances in production of cured meat products and of mechanically deboned meat, so-called MDM (poultry and pork meat), may serve as an example of such procedures. It refers especially to homogenous products such as frankfurter-type sausages (*parówki*, *kiełbasy parówkowe* and *serdelki*) (Tyburcy *et al.* 2005).

To obtain appropriate yield or to lower thermal losses, improve fat and water emulsification and obtain or preserve appropriate colour and stability of the product, suitable functional additives are used (Rutkowski, Gwiazda 1993). Such additives, being generally employed in the meat industry, include: cellulose (potato, wheat), potato starch, yeast extract, soy protein (concentrate or isolate), blood protein, carrageens, sugar, glucose, flavouring spices and their extracts, stabilisers: E-450 (diphosphates), E-451 (triphosphates), E-452 (polyphosphates), E-331 (sodium citrate), antioxidants: E-315 (iso-ascorbic acid), E-316 (sodium iso-ascorbate), E-300 (L- ascorbic acid), E-301 (sodium ascorbate), preservatives: E-205 (sodium nitrite), E-251 (sodium nitrate), thickeners: E-407 (carrageen), and flavour enhancers: E-621 (sodium glutamate) (Słowiński 1996, own information).

Interactions occurring between the main components of batter determine the water-holding capacity, emulsion stability, and shape the rheological properties of batter texture and, in consequence, consistency of the final product (Makała 1997). Extraction of muscular proteins, mainly of myosin and actomyosin and sol formation, occurs solely at the presence of salts, increasing ionic strength of the environment (Theno, Siegel, Schmid 1978). The increase of salt addition causes increase of ionic strength and is a factor affecting the quality of homogenous batter emulsion. The addition of salts to meat batter causes a rise of the degree of fat phase dispersion (Makała 1995, 1996). In the case of bloc products, formed from greater pieces of meat, the concentration of brine is a factor which affects the degree of meat bloc binding (Olkiewicz 1997).

The addition of functional substances or replacers, e.g. of fat, during the manufacturing process of cured meat products is reflected in the texture and sensory quality of the final product (Piotrowska *et al.* 2005). Phosphates, as used in production of finely comminuted and homogenised sausages, improve water-binding capacity and emulsion stability, which has a favourable effect on the quality of the product (Tyszkiewicz and Tyszkiewicz 1972, Rutkowski and Gwiazda 1993). The addition of diphosphates and polyphosphates in the quantity of 3 g kg^{-1} – which corresponds to the rate of the added phosphorus: 1.6 g of P_2O_5 – caused reaching the maximum value of the studied rheological parameters in the case of sausages produced from chicken meat; further increase of phosphates addition did not improve the texture of the product (Zawadzka *et al.* Kern-Jędrychowski 2003). Similar conclusions could be drawn from the examination of phosphate mixture with a new composition (Makała *et al.* 2005). On the other hand, the addition of 0.3% of carrageen and 0.5% of phosphates allowed producing ham from chicken, with the yield equal to 160% in relation to the weight of meat, characterised by good sensory and technological quality (Słowiński *et al.* 2003). The replacement of tendinous beef meat with hydrated preparation of soy protein concentrate had a significant influence on the rise of thermal loss and decline of the tear strength of slices (Makała, Olkiewicz 1999). Tyszkiewicz *et al*. (1997) conducted studies on the influence of protein and carbohydrate fat replacers on the texture of comminuted meat products and their acceptance by consumers, and it was revealed that decrease of fat content did not affect negatively the texture only when the additional quantity of water was bound in the structure of the product. Such texture parameters as humidity, hardness and springiness were significantly correlated with the level of fat substitution.

From the studies by Ostrowska and Olkiewicz (1999) it follows that, apart from lowering of the fat content in the model product, the substitution of fat with polysaccharide-protein replacer caused significant changes in its physicochemical characteristics: the level of protein was changed, the water content was increased, plasticity (*P*) was decreased, elasticity (*E*), fluidity (*F*) and thermal loss were increased, the parameters of profile analysis of texture: hardness, cohesiveness, gumminess and chewiness were deteriorated. The application of replacer with a high degree of hydration of protein component was accompanied by a significant deterioration of rheological characteristics and the degree of lowering of the rheological quality, and the degree of bloc binding was significantly dependent on the participation of meat and fat in the raw material formulation and the assumed level of fat substitution. It was observed that increase of protein content in the product caused inhibition of the decline of plasticity (*P*) and rise of elasticity (*E*) and fluidity (*F*), caused by fat replacement, so weakening of the rate of deterioration of texture and bloc binding together with the rise of level of substitution. Similar conclusions may be drawn from the studies by Tyszkiewicz *et al*. (2006) on the factors shaping the rheological properties of cured meat products in the form of bloc. It follows that fat content in the product affects all the examined rheological parameters but it has the strongest effect on elasticity (E) and fluidity (F); the degree of protein hydration has an influence on plasticity (P) and elasticity (E). The addition of polyphosphates affects the elasticity (E) and fluidity (F) most strongly.

It was revealed that the combined application of functional proteins (soy or casein) and microbiological trans-glutaminase improved water-holding capacity as well as tear force of the model product with the participation of PSE meat (Olkiewicz and Kłossowska 2002). Also, other studies confirmed the effectiveness of trans-glutaminase addition in improving the texture (hardness and chewiness) of model sausage with the participation of mechanically deboned poultry meat (MDPM) (Cegiełka and Flis 2005).

From the above abbreviated information, we may conclude about the unquestionable fact of the effect of reasonably employed functional substances – apart from the basic components (water, protein, fat) – on the quality of meat products, including their rheological properties.

JUSTIFICATION FOR UNDERTAKING THE STUDIES AND THE PURPOSE OF THE WORK

Studies on the effect of selected functional additives on model meat products have been conducted at the Meat and Fats Research Institute for many years. The results of the mentioned studies have been widely presented in papers published in the Annals of the Institute and cited above. To determine the occurring relationships in a univocal way, the number of factors in such model studies is limited to 2-3, and the model of the product is, as a rule, very simplified. The problem is different in the case of market products where we have to deal with many products such as sausages of frankfurter type (*parówka* or *parówkowa*), being often much differentiated in respect of formulation within the same assortment group. There is a strong competition among the producers and we may suppose that there are different methods employed in order to make the products cheaper, more attractive and outstanding. The Regulation of the Minister of Agriculture and Rural Development (Official Journal of Laws No. 220, item 1856) on labelling of food products imposed a duty on the producers to determine the quantity of meat in products intended for direct consumption (Tyszkiewicz 2005). The raw material composition of the product, together with all additives, must be visible on the label on the packed product. The obligatory labelling of meat products was aimed at enabling the consumers to expect that all information significant for protection of his health would be found on the label and they could be informed what product they were buying, what was its raw material composition and what functional additives were contained in the mentioned product, so they could have free choice of the product in accordance with their nutritional preferences and habits (Gwiazda and Dąbrowski 2003).

In connection with the above fact, comprehensive studies of selected popular market meat products were undertaken; the first studies included sausages produced from chopped and finely minced batter and smoked meat products (hams, cured pork shoulders and sirloins) with a high yield, with the aim to examine comprehensively their quality, including basic chemical composition, the level of the declared functional additives, sensory evaluation and evaluation of the correctness of producers declaration, as being inserted on the product labels.

The specificity of the selected assortments determined the selection of the methods for examination of rheological characteristics. For homogenous products (small diameters) with intentionally comminuted tissue structure as a result of chopping, and being mainly consumed as hot meal, the method of texture profile analysis (TPA) was employed. In the discussed method, the parameters exhibit the functions and impressions connected with crushing and mastification of the product pieces in the mouth. In the case of smoked meat products, we deal with products manufactured from anatomic elements of animal (loin, ham, shoulder, sirloin), characterised by preserved tissue structure. Such products are consumed as a cold product, in the form of slices, constituting the layer between bread or roll slices. The employed method of rheological test must consider the sensations characteristic of fragmentation via biting off the pieces. In the discussed case, a completely different research method was applied, i.e. the method of multiple, continuously increasing stress and relaxation (CASRA method) which implements the process of simultaneous cutting and compression of the product.

In the present work, being a fragment of the conducted studies, attempts were undertaken to establish the relationships between the structure of the product and the material of which it was composed, and the relations between the rheological parameters of the employed research methods (TPA, CASRA) and the content of functional components in the studied meat products (homogenous and comminuted ones, and in the smoked products), and attempts to determine their interactions.

RESEARCH MATERIAL AND METHODOLOGY OF THE STUDIES

During the autumn-winter period of 2005/2006, the following products were bought in the “Geant” trade network:

- 17 samples of homogenous and comminuted meat products of small size, consumed mainly “when hot” (group I), including:
- 12 samples of frankfurter-type sausages (*parówki*);
- 4 samples of *parówkowa* sausage and *serdelki*;
- 1 sample of medium-comminuted small sausages and
- 2 samples of bologna-type sausage (*mortadela*), being produced in great diameter casings and consumed “cold”.
- 12 samples of smoked meat products in nets or casings (group II), including:
- 4 samples of hams;
- 4 samples of sirloin (including 2 high-yield ones)
- 4 samples of cured pork shoulder (*baleron*) (including 2 high-yield ones).

In the purchased products, the following parameters were determined:

- basic chemical composition, with the determination of the following content:

- Water (W), by the drying method, at temperature of 105°C, acc. to PN-ISO 1442:2000,
- Fat (RFC), by Soxhlet method, using Soxtec equipment of Tecator company, acc. to PN-ISO 1444:2000,
- Total protein (P), by Kjeldahl method, using Kjeltec equipment of Tecator company, acc. to PN-75/A-04018,
- NaCl (NC) – by potentiometric method acc. to PN-ISO 1841-2;2002,
- Phosphorus (PM) - by weight method acc. to PN-A-82060:1999;
- Starch (SC) – by the method acc. to PN-85/A-82059;
- Collagen (CC) – by the method for determination of hydroxyproline acc. to PN-ISO 3496:2000, and
- Feder number, being the ratio of water to protein content in the product (W/P);

\- the following rheological tests were carried out:

- for the products from group I, including sausages with small diameters and with chopped or finely comminuted batter – TPA test (Texture Profile Analysis) (Bourne *et al.* 1966, Crystall *et al.* 1994), using UTM Zwick 1440 MOPS. For examination of objects with small diameters, mainly of frankfurter-type sausages, the test conditions were modified, decreasing the dimensions of the samples. Parameters of the test included: fracturability-force, fracturability-deformation, hardness, cohesiveness, gumminess, springiness and chewiness. Measurement conditions were as follows: deformation value – 80%, traverse velocity – 60 mm min^{-1}; dimensions of samples: height – 10 mm; diameter – 14 mm;
- for the products of group II, which included sausages of higher size – smoked meat products and bologna-type sausage (*mortadela*) – CASRA test (Continuously Alternated Stress – Relax Analysis), using UTM Zwick 1440 MOPS, calculating the following parameters from the obtained rheograms: plasticity (P), elasticity (E) and fluidity (F) (Tyszkiewicz *et al.* 1997). Measurement conditions were as follows: traverse velocity between bites: 120 mm min^{-1} and over bite duration: 2 mm min^{-1}; force unit: F_1 = 1 N; force increment ΔF: 1N; stress and relaxation time – t_o = 15 s each time; mandrel surface area: S = 40 x 10^{-5} m^2 (21); and

\- Sensory evaluation, being the subject of separate elaboration, was also performed.

The obtained results of chemical analyses and rheological tests presented in Tables 1-6 are the means from two repetitions. The results of the studies were subjected to the following statistical tests: linear regression analysis, multiple regression analysis and analysis of the principal component (Principal Component Analysis – PCA), using statistical package Statgraphics Plus for Windows ver.3.1.

Table 1. Results of texture profile analysis (TPA) and chemical composition – first group of meat product

Product	Fracturability-force (Ff) (N)	Fracturability-deformation (Fd) (%)	Hardness (Ha) (N)	Cohesiveness (Co)	Gumminess (Gu) (N)	Springiness (Sp) (mm)	Chewiness (Ch) (Nmm)	Feder number (W/P)	Fat content (RFC) (%)	NaCl content (NC) (%)	Phosphorus content (PM) (g/kg)	Starch content (SC) (%)	Collagen (CC) (%)
1	16,38	49,36	17,23	0,118	2,04	1,87	4,97	5,44	26,6	1,60	3,48	1,62	1,94
2	21,95	55,68	18,89	0,158	3,03	2,96	9,35	5,08	20,7	1,48	3,02	0,40	0,99
3	40,08	56,13	33,24	0,131	4,40	2,79	12,21	4,07	23,4	2,00	2,90	0,62	2,17
4	10,18	47,33	13,80	0,115	1,59	1,53	2,44	6,94	26,9	1,65	2,60	1,98	1,26
5	28,62	51,10	37,63	0,157	8,02	2,70	15,55	4,08	19,6	2,04	5,02	2,05	1,81
6	22,93	47,93	23,83	0,119	2,56	1,90	4,90	5,05	22,2	1,62	3,37	0,36	2,15
7	38,45	55,80	30,78	0,139	3,92	2,95	11,60	3,80	19,1	2,19	4,02	2,36	2,05
8	30,54	52,63	28,50	0,131	3,75	2,61	9,80	4,90	19,7	1,70	2,30	2,99	2,27
9	14,65	50,04	16,73	0,129	2,17	2,15	4,68	5,81	21	1,78	3,78	3,30	2,13
10	29,07	60,43	21,12	0,143	3,97	3,32	7,83	6,61	2,9	1,82	4,61	6,54	2,03
11	26,08	52,97	33,41	0,150	5,01	2,72	13,65	4,15	32,8	2,25	4,37	3,23	0,99
12	19,68	52,35	17,36	0,136	2,38	2,51	5,98	6,06	25,9	1,91	2,90	2,63	1,88
13	27,04	57,60	28,93	0,141	4,11	2,77	11,43	5,07	18,1	1,67	2,80	2,50	1,16
14	16,87	54,84	19,80	0,143	2,84	2,34	6,72	6,19	16,9	2,25	3,32	4,00	2,03
15	23,12	54,25	21,61	0,144	3,12	2,76	8,63	5,33	23,7	2,10	3,01	2,65	1,99
16	23,93	51,84	24,70	0,128	2,94	2,17	6,38	5,40	24,5	2,04	3,11	2,77	1,83
17	15,20	53,25	19,78	0,123	1,81	1,42	2,60	6,95	24,5	1,99	2,70	2,69	1,80

Table 2. Results of rheological characteristics (CASRA method) and chemical composition – second group of meat product

Product	Plasticity (P) (x10^5 N m^{-2})	Elasticity (E) (x10^{-7} m^2 N^{-1})	Fluidity (F) (x10^{-8} m^2 $N^{-1}s^{-1}$)	Feder number (W/B)	Fat content (RFC) (%)	NaCl content (NC) (%)	Phosphorus content (PM) (g kg^{-1})	Starch content (SC) (%)	Collagen content (CC) (%)
1	4,458	11,150	4,632	4,1	8,2	2,30	5,57	0,39	0,80
2	3,375	11,912	4,140	5,7	3,0	1,96	6,13	3,43	1,76
3	5,125	8,260	3,280	4,1	1,8	2,51	6,73	1,13	0,94
4	4,375	8,104	4,240	5,1	2,1	2,67	7,42	0,48	0,69
5	5,125	7,343	4,670	4,5	11,5	2,46	7,08	0,00	0,62
6	4,833	9,105	3,430	4,6	5,6	2,55	7,60	1,00	0,72
7	1,564	13,755	4,628	6,7	19,7	1,85	3,30	3,54	1,85
8	1,625	15,274	6,110	6,1	17,6	1,70	4,12	2,88	2,58
9	4,350	7,773	3,710	4,2	10,8	2,16	2,27	1,21	1,30
10	3,188	9,907	3,640	4,1	4,4	2,42	1,67	0,62	1,00
11	5,565	6,758	4,026	5,4	9,0	2,27	2,32	2,00	0,78

Table 3. Correlations between rheological and chemical parameters

Rheological parameters \ Chemical parameters		Feder number (W/P)	Fat content (RFC) (%)	Salt content (NC) (%)	Phosphorus content (PM) (%)	Starch content (SC) (%)	Collagen content (CC) (%)
TPA method	Fracturability (Ff) (N)	–0,761 ***	–0,231 ns	0,292 ns	0,245 ns	–0,048 ns	0,235 ns
	ε – Fracturability (Fd) (%)	–0,113 ns	–0,626 **	–0,239 ns	–0,120 ns	0,447 ns	–0,035 ns
	Hardness (Ha) (N)	–0,833 ***	0,004 ns	0,430 ns	0,411 ns	–0,115 ns	0,005 ns
	Cohesiveness (Co)	–0,421 ns	–0,266 ns	0,320 ns	0,488 *	0,179 ns	–0,334 ns
	Gumminess (Gu) (N)	–0,678 **	–0,187 ns	0,353 ns	0,637 **	0,053 ns	–0,071 ns
	Springiness (Sp) (mm)	–0,509 *	–0,504 *	0,196 ns	0,391 ns	0,280 ns	–0,023 ns
	Chewiness (Ch) (Nmm)	–0,836 ***	–0,087 ns	0,359 ns	0,473 *	–0,049 ns	–0,163 ns
CASRA method	Plasticity (P) (x 105 N m^{-2})	–0,658 **	–0,386 ns	0,353 ns	–0,089 ns	–0,653 *	–0,828 ***
	Elasticity (E) (x 10^{-7} m^2 N^{-1})	0,639 *	0,357 ns	–0,365 ns	0,136 ns	0,689 **	0,829 ***

Significance level: ns not significance, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table 4. Parameters of Multiple Regression Analysis

	Parameters	Multiple regression $Y_i = aX_1 + bX_2 + cX_3 + dX_4 + eX_5 + fX_6$	Correlation coefficient
TPA method	Fracturability – force (Ff) (N)	Y_1 = 78,60 – 7,96(W/P) – 0,66(RFC) + 6,39(NC) + 3,64(PM) + + 0,58 (SC) + 0,45 (CC)	0,923 ***
	Fracturability – deformation (Fd) (%)	Y_2 = 73,87 – 1,50(W/P) – 0,51 (RFC) + 6,26(NC) –2,32 (PM) + + 0,46 (SC) – 3,76 (CC)	0,882 **
	Hardness (Ha) (N)	Y_3 = 51,91 – 6,09(W/P) – 0,21 (RFC) + 7,13 (NC) – 0,59 (PM) + +0,44 (SC) – 1,91(CC)	0,894**
	Cohesiveness (Co)	Y_4 (x 100) = 17,96 – 0,51(W/P) – 0,12(RFC) + 2,05(NC) + 0,13(PM) – – 0,03(SC) – 1,84(CC)	0,817 *
	Gumminess (Gu) (N)	Y_5 = 7,36 – 0,94(W/P) – 0,07 (RFC) + 1,02 (NC) + 0,59(PM) + + 0,03(SC) – 0,75(CC)	0,845 *
	Springiness (Sp) (mm)	Y_6 = 6,55 – 0,45(W/P) – 0,05 (RFC) + 0,12(NC) – 0,15(PM) + + 0,14 (SC) – 0,38 (CC)	0,883 **
	Chewiness (Ch) (Nmm)	Y_7 = 31,69 – 3,67 (W/P) – 0,18 (RFC) + 2,72 (NC) – 0,32(PM) + + 0,52(SC) – 2,97(CC)	0,946 ***
CASRA method	Plasticity (P) (x 10^5 N/m^2)	Y_8 = 15,01 – 0,35(W/P) – 0,04 (RFC) – 2,86 (NC) + 0,10 (PM) + + 0,14(SC) – 2,74X_{78}	0,923 **
	Elasticity (P) (x 10^{-7} m^2/N)	Y_9 = –8,30 + 0,19X_{19} + 0,07 (RFC) + 4,30(NC) + 0,13 (PM) – – 0,04 (SC) + 5,29(CC)	0,899*
	Fluidity (F) (x 10^{-8} m^2/Ns)	Y_{10} = 2,86 + 0,736(W/P) + 0,01(RFC) – 1,11(NC) + 0,05 (PM) – – 0,83 (SC) + 0,95 (CC)	0,926 **

where: X_1 – Feder number (W/P), X_2 – Fat content (RFC), X_3 – Salt content (NC), X_4 – Phosphorus content (PM), X_5 – Starch content (SC), X_6 – Collagen content (CC).

Table 5. Coefficient of Eigenvalue (loadings) for two First Components (PC 1 and PC 2) for first group products

Variables	PC 1	(%)	PC 2	(%)
Feder number (W/P)	0,3076	9,43	0,3627	12,50 *
Fat content (RFC) (%)	0,1240	3,80	0,5173	17,83 *
NaCl content (NC) (%)	0,1825	5,60	0,0324	1,12
Phosphorus content (PM (g/kg)	0,2374	7,28	0,0813	2,80
Starch content (SC) (%)	0,0575	1,76	0,5341	18,41 *
Collagen content (CC) (%)	0,0092	0,28	0,1714	5,91
Fracturability–force (Ff) (N)	0,3381	10,37 *	0,0492	1,70
Fracturability–deformation (Fd) (%)	0,2438	7,48	0,3741	12,90 *
Hardness (Ha) (N)	0,3479	10,67 *	0,2343	8,08
Cohesiveness (Co)	0,3157	9,68	0,0905	3,12
Gumminess (Gu) (N)	0,3630	11,13 *	0,1049	3,62
Springiness (Sp) (mm)	0,3446	10,57 *	0,1981	6,83
Chewiness (Ch) (Nmm)	0,3897	11,95 *	0,1508	5,20
$\sum \lvert \text{loadings} \rvert$	3,2610 = 100,00		2,9011 = 100,00	

* Variables with loading ≥ 10% of the sum absolute loading (Σ/loadings/).

Table 6. Coefficient of Eigenvalue (loadings) for two First Components (PC 1 and PC 2) for second group meat products

Variables	PC 1	(%)	PC 2	(%)
Plasticity (P) (x 10^5 N m^{-2})	0,363	12,69 *	0,253	9,81
Elasticity (E) (x 10^{-7} m^2 N^{-1})	0,365	12,73 *	0,352	13,68 *
Fluidity (F) (x 10^{-8} m^2 $N^{-1}s^{-1}$)	0,309	10,77 *	0,158	6,14
Fat content (RFC) (%)	0,304	10,63 *	0,417	16,19 *
Feder number (W/P)	0,362	12,65 *	0,150	5,80
Salt content (NC) (%)	0,327	11,42 *	0,432	16,75 *
Phosphorus content (PM) (%)	0,053	1,86	0,618	23,97 *
Starch content (SC) (%)	0,369	12,88 *	0,136	5,27
Collagen content (CC) (%)	0,412	14,37 *	0,062	2,39
$\sum$ |loadings|	2,8649 = 100,00 %		2,5774 – 100,00	

* Variables with loading ≥ 10% of the sum absolute loading (Σ/loadings/).

RESULTS AND DISCUSSION

The main factors shaping the quality of meat products include, undoubtedly, the basic components of the formulation: water, protein and fat. It should be stressed that they are present in the product in absolutely dominating quantities and their participation in basic composition is balanced to 100%. Their mutual interactions decide on the quality of the protein-water-fat matrix of the meat product, especially of a homogenous one. Subsequent treatments, e.g. addition of water, limitation of fat content, introduction of functional additives, change only the proportions of the basic components. By this, they affect the quality of the product in a modifying way, improve and hide possible defects of the product, or simply increase its yield or render new properties, e.g. springiness and improvement of the degree of bloc binding.

Absolute Feder number, being the ratio of water content (*W*) and protein content (*P*) in the meat, is characteristic of particular muscles or group of muscles in slaughter animals. It constitutes an index of protein hydration and is directly related to the yield of the products. For raw ham meat, the value of Feder number is about 3.5. After many-week process of ham ripening, where dehydration of the product takes place, Feder number is lowered to the level of 1.8. In the case of the products examined in the present work (Tab. 1 and 2), we deal – in the manufacturing process – with adding water directly to the batter during chopping, or introducing it to the muscles during brine curing. These procedures lead to a rise of protein hydration. Depending on the amount of water added and the degree of meat protein substitution with non-meat protein, different degrees of hydration in the examined products were obtained. It was manifested by differentiated values of Feder number, from low values up to high values, amounting to 3.80-6.95 in the case of products from group I, and to 4.1-6.7 for samples from group II.

It was also accompanied by distinctly differentiated content of the remaining determined components (Tab. 1 and 2). In group I, the content of fat in the products was from 18.1% to 32.8%, with one exception for which fat content was only 2.9%. For products of group II, where products with preserved tissue structure dominated (hams, loins, cured pork shoulder products), fat content was decisively lower (by about 10%); it was found within the limits of 1.8-19.7%.

NaCl content amounted to 1.84-2.25% for the products of group I and to 1.70-2.70% for the products of group II. Phosphorus level was found within the limits of 2.30-5.02 g kg^{-1} for group I and 1.70-7.6 g kg^{-1} for group II. The determined starch content amounted to 0.36-6.54% for group I and to 0.00-3.50% for group II, while collagen content was equal to 0.99-2.27% for the product of group I and to 0.60-2.60% for group II.

Correlation analysis between rheological parameters of the studied products of group I (parameters of TPA method) and group II (parameters of CASRA method) and chemical discriminants (Feder number and content of fat, NaCl, phosphorus, starch and collagen) was carried out (Tab. 3). Feder number was best correlated with the rheological parameters. Except for fracturability-deformation and cohesiveness, for which a lack of correlation was found, the coefficient of linear correlation for the remaining parameters was at least significant ($\alpha \leq 0.05$) and for fracturability-force, hardness and chewiness, the correlation with Feder number was very highly significant ($\alpha \leq 0.001$). The remaining chemical indices did not reveal such good linear correlations with the studied parameters. Some of the studied relationships had a non-linear character. Examples of such relations include curve-line relationships of phosphorus concentration with rheological parameters, revealing a distinct maximum (Fig. 6). We should also mention the following relationships: highly significant negative correlation of fat content with fracturability-deformation and significantly negative correlation with springiness, highly significant correlation of phosphorus with gumminess and significant with cohesiveness and chewiness, and also correlation of starch content with parameters of CASRA method: highly significant with elasticity and significant with plasticity and fluidity. NaCl content was significantly negatively correlated only with fluidity. Special attention should be paid to the correlation of collagen content with parameters of CASRA method: very highly significant negative correlation with plasticity and positive with elasticity, and significant positive correlation with fluidity. Collagen content in the products with parameters of TPA method was not correlated. The selected relationships of the parameters of TPA method are presented in diagrams 1, 2 and 3. The run of the selected relationships of CASRA method parameters and Feder number, fat, phosphorus and collagen content is given in diagrams 4, 5, 6 and 7.

Analysis of multiple regression was carried out with the aim to specify the effect of the determined chemical discriminants on the studied parameters of TPA and CASRA method. The results of the mentioned analysis are given in Table 4 where the equations of multiple regression for all the examined rheological parameters are presented: seven for TPA method and three for CASRA method, where X_1 – Feder number (W/P), X_2 – fat content (RFC), X_3 – salt content (NC), X_4 – phosphorus content (PM), X_5 – starch content (SC) and X_6 – collagen content (CC). Three of the evaluated dependences of the studied parameters on the independent variables mentioned above showed significant correlations (cohesiveness, gumminess and elasticity), four – highly significant correlations (fracturability – deformation, hardness, springiness and plasticity) and two – very highly significant correlations (fracturability-force and chewiness).

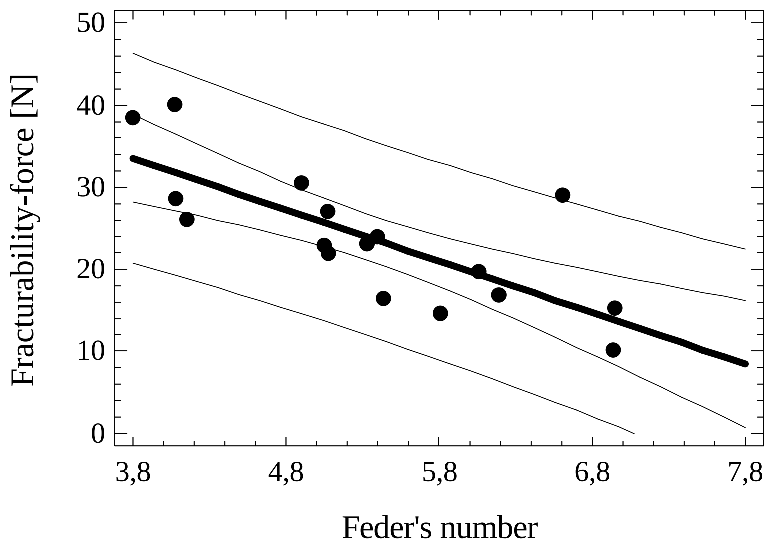

Fig. 1. Correlation between fracturability-force and Feder's number

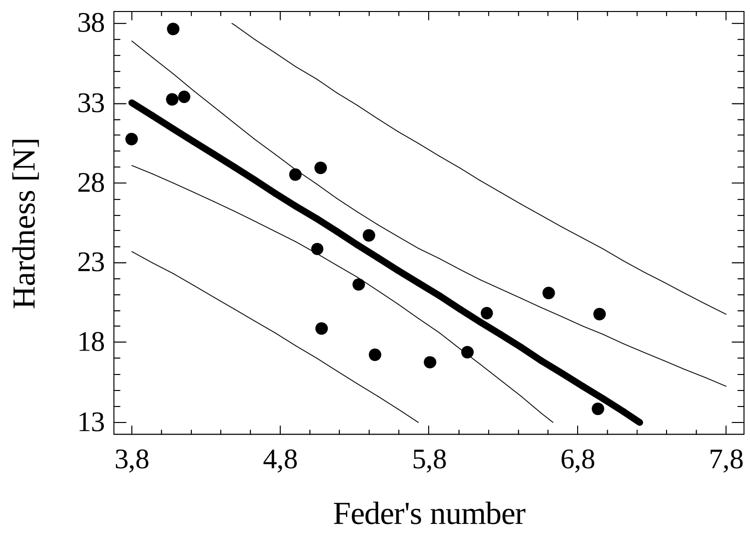

Fig. 2. Correlation between hardness and Feder's number

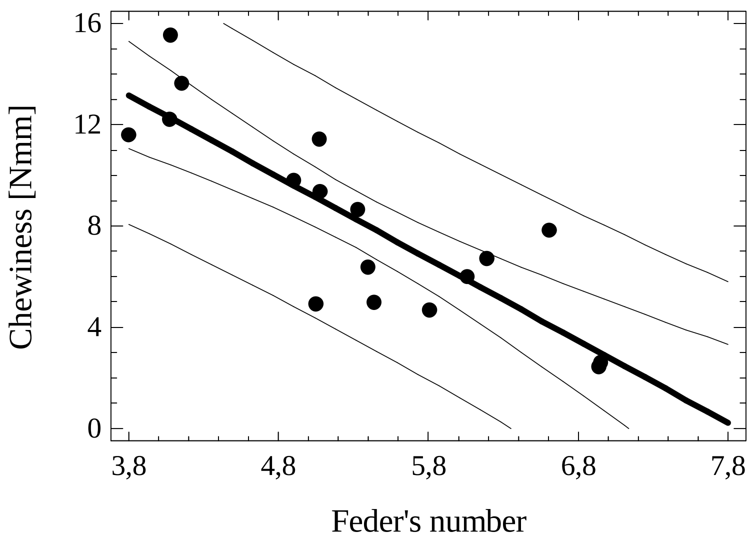

Fig. 3. Correlation between chewiness and Feder's number

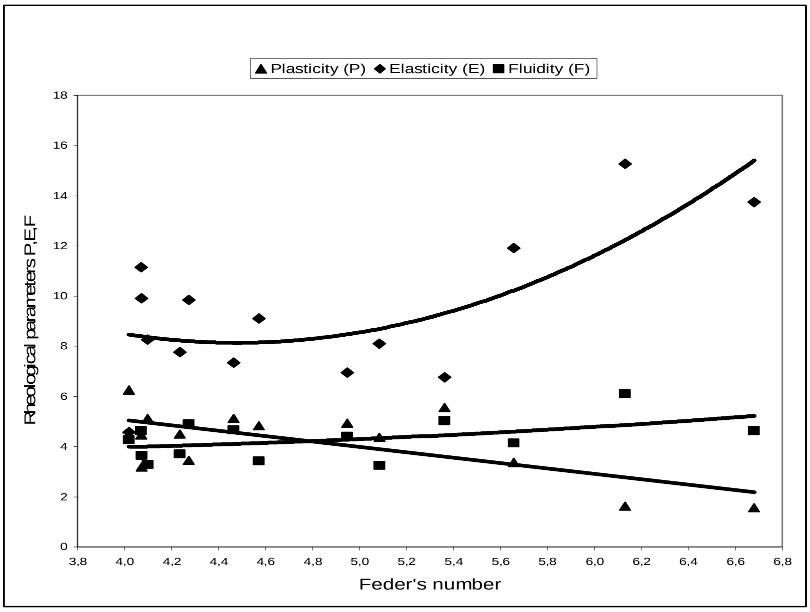

Fig. 4. Relation between rheological parameters and Feder's number

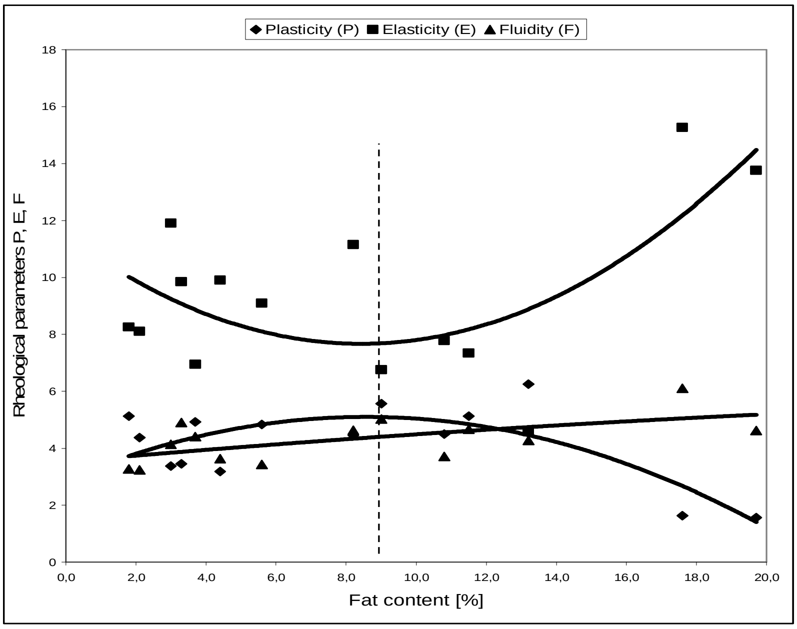

Fig. 5. Relation between rheological parameters and fat content

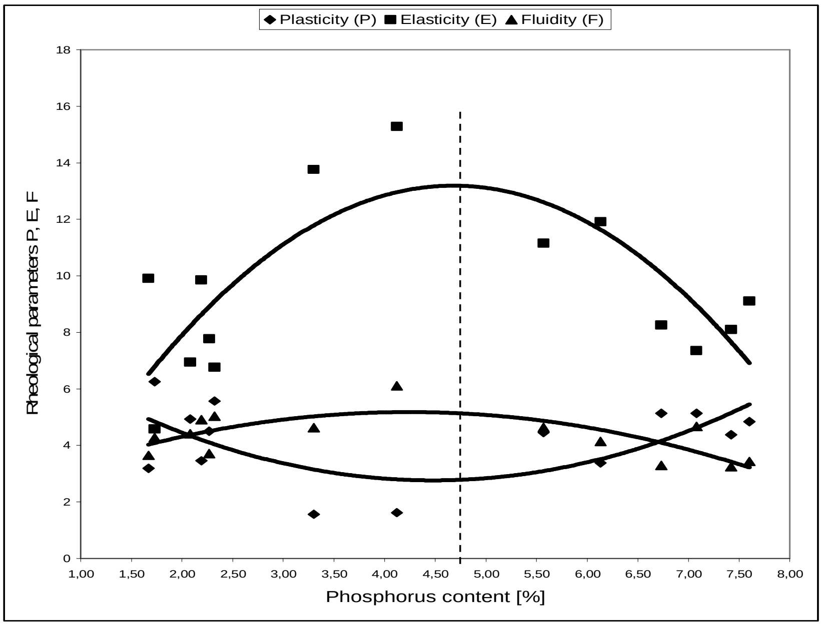

Fig. 6. Relation between rheological parameters and phosphorus content

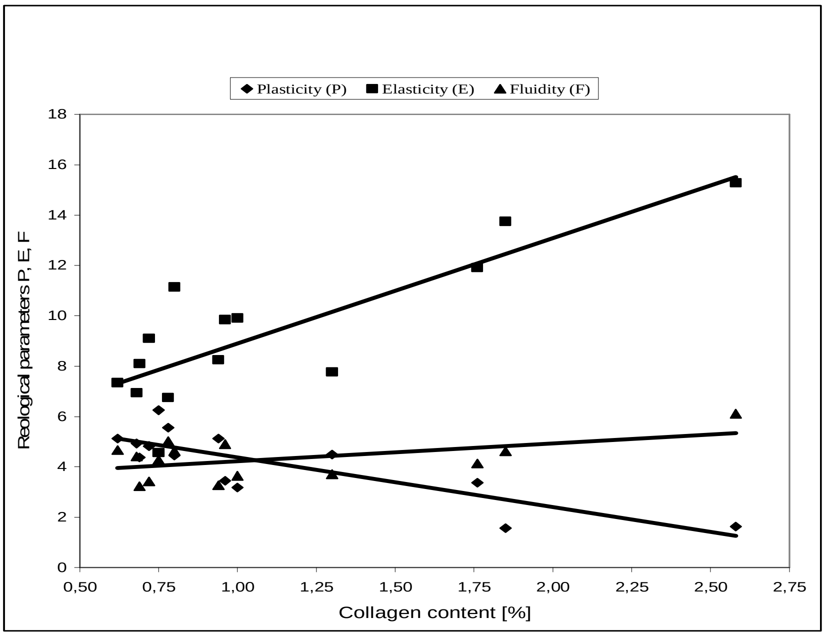

Fig. 7. Relation between rheological parameters and collagen content

Analysis of principal components of the studied products from group I (frankfurter-type sausages, *parówkowe* and small sausages) demonstrated that the first principal component – PC 1 – covered 46.10% of the total variability and the second principal component – PC 2 – the successive 18.97% of variability. For PC 1, the following variables were important: fracturability-force, hardness, gumminess, springiness and chewiness, i.e. most of the parameters of the TPA method. For PC 2, the most important variables included: fracturability-deformation (TPA method) and Feder number, fat content and starch content, i.e. discriminants of chemical composition, modifying significantly the rheological properties (Tab. 5). Distribution of the principal components in bi-dimensional space and of the points representing the products of group I are given in bi-plot (Fig. 8). They show the mutual correlations and relationships between the studied discriminants. Analysis of bi-plot and data of Tab. 1 shows distinctly the effect of the chemical discriminants mentioned above on the studied products; it is confirmed by the distribution of the products on the diagram (points in two-dimensional space).

Products marked with “3”, “5”, “7”, and “11”, situated in the lower left corner of bi-plot, possess the lowest values of Feder number: 3.8-4.2. The products “2”, “8”, “13”, “15” and “16”, with Feder number equal to 5.8-6.2, are located somewhat more to the right and slightly upwards. We will find the products marked with “9”, “12” and “14” (Feder number 5.8-6.2) to the right from them, and slightly upwards.

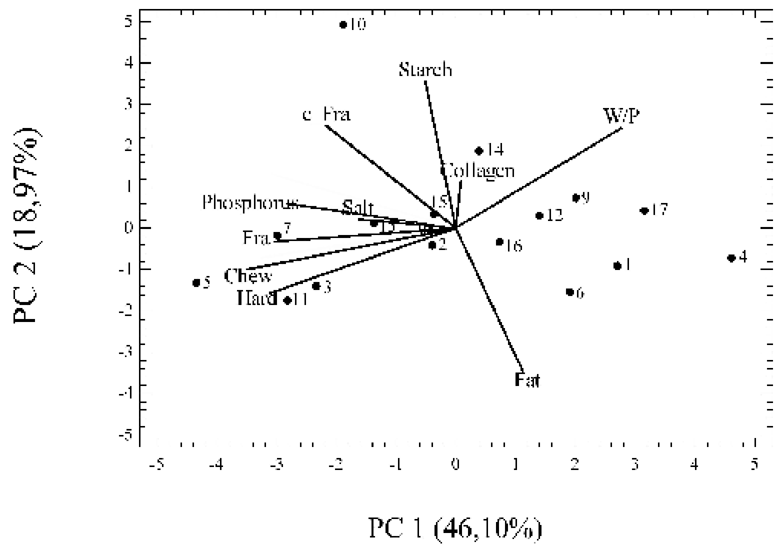

Fig. 8. Biplot for the first group of meat products

Most extremely to the right, there are the products “1”, “4”, “6” and “17”, with the highest Feder number, amounting to 6.9-7.0. Such a way of the products distribution corresponds generally to decreasing values of TPA method parameters which are inversely proportionally correlated with Feder number and decrease together with the increase of the mentioned feature (see: TPA from Tab. 1). Product marked with “10” is found in the upper left quarter of the diagram in spite of the fact that is possesses Feder number equal to 6.6. In this case, we may see a significant effect of the highest starch content in the product. A similar situation refers to products: “14”, “9” and “8”, with relatively high starch content (2.99-4.00), situated in the upper part of the diagram. On the other hand, the products “5”, “7”, “10” and “11”, with the highest phosphorus content, the level of which is positively correlated with TPA method parameters, are found in the left extreme part of the diagram. Further to the right, products with decreasing phosphorus content are found.

For the studied products of group II (smoked meat products and bologna-type sausages of greater size in nets and casings), the analysis of principal components (PCA) was also carried out. Two first principal components, PC1 and PC2, covered about 75% of total variability. For PC1, all the examined discriminants were important, except for phosphorus content. For PC2, the following indices were important: elasticity, fat content, salt content and phosphorus content (Tab. 6). Distribution of the principal components and points representing the studied products in bi-dimensional space is given in bi-plot (Fig. 9). We may observe here mutual correlations and relationships between the discriminants of rheological characteristics and determined components, contained in the tested products. Plasticity is negatively correlated with elasticity and fluidity and with collagen and starch content and with Feder number. NaCl and phosphorus content is negatively correlated with fat content and fluidity.

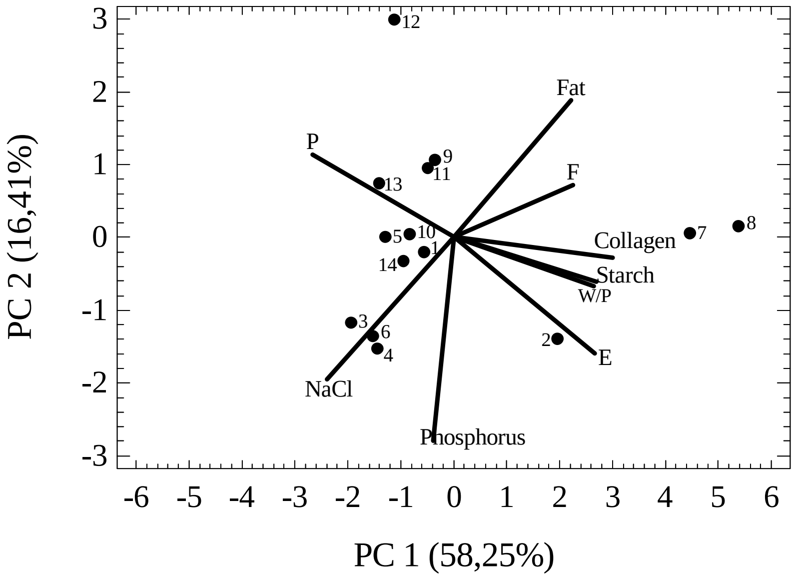

Fig. 9. Biplot for the second group of meat products

On the right side of the bi-plot, there are two products: “7” and “8”, with the highest values of Feder number (6.7 and 6.1), high levels of starch (3.54 and 2.88) and the highest contents of collagen (1.85 and 2.58%) and fat (19.7 and 17.6%). On the left side we find the products with lowering Feder number and decreasing content of collagen, fat and starch. The products marked with “1”, “5”, “10” and “14” are characterised by low values of Feder number. Product “3”, with Feder number equal to 4.1 and one of the highest NaCl contents, is found as the last one, on the left lower side of the diagram. In the lower part of the diagram, more to the right, we find the products: “3”, “4”, “6”, possessing the highest levels of phosphorus and NaCl and a moderate level of plasticity. Product “2”, possessing additionally a high starch content (3.43%), is shifted distinctly to the right (see Tab.2).

In the upper part of the diagram, on its left side, the product '12" is found: it is characterised by the extreme levels of the studied discriminants: the highest value of plasticity (6.250 x 10^5 N/m^2), low value of elasticity (4.576 x 10^{-7} m^2/N) and fluidity (4.270 x 10^{-8} m^2/Ns), and the lowest values of NaCl (1.73%), phosphorus (1.73%), starch (0.52%) and collagen (0.75%). The remaining products – due to more equalised levels of rheological parameters and content of the studied components – are situated more centrally, more closely to the crossing of both axes of the diagram: horizontal – the first principal componential (PC1) and vertical – the second principal componential (PC2).

SUMMING UP AND CONCLUSIONS

1. The examined market meat products of both groups reveal a high variability of the tested chemical discriminants and rheological parameters, which results, *inter alias*, from differentiated raw material composition, different degree of protein hydration and level of addition of the selected functional substances.
2. The conducted correlation analysis of the rheological parameters of the studied products showed that the Feder number was best correlated with the rheological parameters. The remaining chemical discriminants did not reveal such good linear correlations with the examined parameters. It was confirmed by earlier studies which demonstrated that a part of relationship was of a non-linear character, showing minimums and maximums.
3. Analysis of multiple regression allowed developing the equations of multiple regression with the main chemical discriminants of the studied products (Feder number, and content of fat, NaCl, phosphorus, starch and collagen) for all studied rheological parameters: seven for TPA method and three for CASRA method. Three of the evaluated relationships between the studied parameters and the independent variables mentioned above revealed significant correlations (cohesiveness, gumminess and elasticity), four – highly significant correlations (fracturability-deformation, hardness, springiness and plasticity) and two of them – very highly significant correlations (fracturability-force and chewiness).
4. The abovementioned correlations and interactions between the studied rheological parameters and functional components of the studied products are well presented on "bi-plots", being a result of the conducted analysis of the principal components (PCA). They allow relating the chemical composition of the product to its parameters of rheological characteristics.

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WPŁYW PODSTAWOWEGO SKŁADU CHEMICZNEGO I DODATKÓW FUNKCJONALNYCH NA CHARAKTERYSTYKĘ REOLOGICZNĄ WYBRANYCH PRODUKTÓW MIĘSNYCH

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Streszczenie. Prowadzono kompleksowe badania wybranych popularnych rynkowych produktów mięsnych jak parówki, kiełbasa parówkowa i serdelowa (grupa I – 17 prób) oraz wędzonki, a także homogenne mortadele większych średnicach (grupa II – 14 prób) w celu wszechstronnego przebadania ich jakości. Podjęto próbę powiązania parametrów reologicznych stosowanych metod badawczych (TPA, CASRA) z poziomem składników funkcjonalnych zawartych w badanych produktach mięsnych oraz próbę określenia ich wpływu na parametry reologiczne. Badano: podstawowy skład chemiczny oraz wyliczono niemianowaną liczbę Federa (W/P), wykonano badania reologiczne. Przebadane rynkowe produkty mięsne obu grup wykazały dużą zmienność badanych wyróżników chemicznych i parametrów reologicznych, co między innymi wynika ze zróżnicowanych składów surowcowych, różnego stopnia uwodnienia białka i wielkości poziomu dodatku wybranych substancji funkcjonalnych. Najlepiej skorelowana z parametrami reologicznymi była liczba Federa. Analiza regresji wielokrotnej pozwoliła na opracowanie równań regresji wielokrotnej dla parametrów reologicznych z głównymi wyróżnikami chemicznymi (liczba Federa, oraz zawartość tłuszczu, NaCl, fosforu, skrobii i kolagenu) badanych produktów. Wykazane zależności korelacyjne i interakcje pomiędzy parametrami reologicznymi i składnikami funkcjonalnymi badanych produktów dobrze przedstawiono na „biplotach” będących wynikiem przeprowadzonej analizy składowych głównych (PCA), co pozwoliło na powiązanie ze sobą składu chemicznego produktu z parametrami charakterystyki reologicznej.

Słowa kluczowe: produkty mięsne, skład recepturowy, dodatki funkcjonalne, charakterystyka reologiczna, analiza składowych głównych (PCA)