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PREDICTIVE FOOD RHEOLOGY. FACTORS SHAPING RHEOLOGICAL PROPERTIES OF BLOCK CURED MEAT PRODUCTS

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Abstract. The influence of the conditions of thermal treatment, fat content and protein hydration as well as polyphosphate addition on the rheological state of model block meat products, characterised with CASRA analysis parameters, i.e. plasticity (*P*), elasticity (*E*) and fluidity (*F*) was tested on an extensive and diversified experimental material. It has been found and stated that the conditions of the thermal treatment affect mostly the plasticity (*P*) – the most important parameter from the point of view of a food technician, determining the product block behaviour during slicing, the fat content affects all the examined rheological parameters, but mostly the elasticity (*E*) and fluidity (*F*), the protein hydration affects the plasticity (*P*) and elasticity (*E*) and the addition of polyphosphates affects mostly the elasticity (*E*) and fluidity (F). We have succeeded in integrating effectively the conditions of thermal treatment, i.e. temperature and time of heating, basing on the Ball-Olson concept applicable to the integration of the thermal sterilisation conditions of microorganisms in canned products. The time of keeping the outer parts of the block in high temperature was taken as the time of heating. With an excellent accuracy the relation of plasticity (*P*) to all the examined factors was described, having regard to the interactions between the thermal treatment conditions and fat content in the product stuffing. With a good accuracy the relation of elasticity (*E*) and fluidity (*F*) to all the examined factors was described. The statistical analysis showed no important interaction between the thermal treatment conditions and fat content in the canned product stuffing. A systematic, relatively simple chemometric proceeding was presented, enabling prediction of quality features of meat products.

Keywords: block meat products, rheological state, predictive food rheology, thermal treatment conditions

INTRODUCTION

Block meat products – a technological term for meat products made in the form of a regular block easy to portion into pieces or – more frequently – slices, in order to be sold in such a form to the end consumer. In the Polish meat industry, as prototypes of block meat products, there appeared canned meat products (ham, shoulder, pork loin, chopped pork and luncheon meat) made for the American market in oblong and pullman type cans. The American recipient opened the cans, sliced the product and then sold it in portions in foil bags. At present, following the pre-selection sales in supermarkets, the packed block cured products have become a popular assortment on the Polish market, too.

The essential quality feature of block meat products (of products of a good consistency) is their texture, both from the points of view of the consumers' preferences and of the block behaviour during slicing. The point is to cut the meat block, without loss of material, into as thin slices as possible and with the application of rapidly slicing machines.

A term of “predictive microbiology" is defined as prediction of growth, survival or inactivation of microorganisms in foodstuffs. Similarly, one can imagine the term of “predictive rheology” defined as prediction of behaviour of a determined subject in the course of the action of forces causing reversible and irreversible changes in its internal structure, shape, size and physical state.

A food technologist, while designing a new product or modifying an existing one, should be able to predict how to develop its quality – selecting the raw materials and additives and setting the conditions of production process – and how the product will behave during processing into finished product.

THE AIM OF THE WORK

The planned examinations were aimed at determining the influence of the basic parameters characterising raw material composition and conditions of thermal treatment on the rheological properties determining the texture of a model meat product representing the so-called block meat products.

MATERIAL

The material for testing was a pork meat product of the luncheon meat type. It was produced in the form of canned products in closed 850 g cylinder cans of size of 99 x 112 mm. The raw material was corned pork meat of different fat contents and potato starch of 2 to 3% added to the stuffing with 15% of water. Polyphosphates in different volumes were also added. The canned products were heated in the conditions typical both for sterilisation and pasteurisation processes. The variables were as follows:

- 7 variants of heating temperature (*T*):
    - 3 for pasteurisation: 75°C, 85°C, 95°C,
    - 4 for sterilisation: 104.1°C (220°F), 112.7°C (235°F), 121.1°C (250°F), 129.4°C (265°F);

- heating time (t):
    - for pasteurisation variant – resultant time, until the temperature in the can centre increased to 72°C,
    - for sterilisation variant – until reaching the sterilisation value from F_0 = 1 min to F_0 = 4 min in the can centre;
- 5 variants of fat contents in stuffing (FC): 6-8%, 12-14%, 18-20%, 24-26%, 30-32%;
- 4 variants of polyphosphate additives (PM) – doses: without additives, 1.5 g kg^{-1}, 3 g kg^{-1}, 5 g kg^{-1} calculated as P_2O_5.

Altogether 7 x 5 x 4 = 140 experimental canned meat variants were produced.

METHODS

During heating and cooling the canned meat, the temperature of the heating medium and in the can centre was monitored, and the sterilisation value F_0 was calculated. After opening the cans, first the thermal loss was weighed and then the block was subjected to rheological and chemical tests.

Rheological examinations

The rheological properties of cured meat products were tested with the Continuously Alternating Stress-Relaxation Analysis (CASRA) described by Tyszkiewicz *et. al.* [9], determining the following parameters: plasticity (P), elasticity (E) and fluidity (F), with the application of UTM Zwick 1440 MOPS. In the CARSA method the plasticity of meat (P) is a rheological parameter determining the strength necessary for destroying the structure of the material of the tested subject, elasticity (E) is a rheological parameter informing about the ability of the material of reversible changes in the shape of the tested subject, and fluidity (F) is a rheological parameter informing about the ability of the material of irreversible changes in the shape of the tested subject.

The conditions of CASRA method were as follows:

- crosshead velocity: between the bites – 120 mm min^{-1} and within the bite 2 mm min^{-1},
- unit force – F_1 = 0.5 N,
- force increment – ΔF = 0.5 N for each next bite,
- duration of stress and relaxation periods – t_0 = 15 s each,
- rectangular punch (2 mm x 20 mm), $S = 4 \cdot 10^{-5}$ m^2,
- modular stress $\sigma_1 = 1{,}25 \cdot 10^4$ N m^{-2}.

Physical and chemical examinations

Immediately after opening the cans, the quantity of the thermal loss (TL) was determined with the weight method, according to the methodology described by Ostrowska and Olkiewicz [2]

The basic chemical composition of the canned product produced in particular variants was checked with the determination of the real contents of:

- water (W) with the drier method in the temperature of 105°C according to PN-ISO 1442:2000 /3/,
- fat (RFC) with the Soxhlet method with the application of the apparatus Soxtec of Tecator Company, according to PN-ISO 1444:2000 /4/,
- total protein (P) with the Kjeldahl method with the application of the apparatus Kjeltec of Tecator Company according to PN-75/A-04018 /5/,
- phosphorus (PM) with the weight method according to PN-A-82060:1999 /6/.

The results were interpreted statistically applying correlation and regression calculations with the application of Statgraphics Plus for Windows.

RESULTS AND THEIR INTERPRETATION

The results were analysed using the correlation calculation to determine relations between the parameters, and the relations were drafted in order to see their character. On the basis of analysis of the diagrams, 4 variants representing the sterilisation temperature of 104.1°C (3% of results) were eliminated, because for this value a gross error of the fluidity parameter (F) was stated.

The results of the correlation analysis for the set of 136 variants are shown in Table 1. As it could have been provided for, the rheological parameters of plasticity (*P*), elasticity (*E*) and fluidity (*F*) are inter-correlated; the elasticity and fluidity – positively and the plasticity – negatively. All the rheological parameters are correlated with the temperature (*T*) of thermal treatment, the elasticity (*E*) with the time of duration of the said processing, too. A high negative correlation coefficient between the temperature (*T*) and time (*t*) of thermal treatment was stated for low, in majority minor correlation coefficients of time of processing with the rheological parameters, which indicates the necessity of a better-though-out analysis of the said relations. All the rheological parameters, however, are strongly correlated with the real fat content (RFC) and, much more weakly – with the phosphorus content (PM) in the product. The last relation is, however, of a non-linear character, since the effective action of polyphosphates on meat structure is limited to their lower doses [10]. There is, moreover, a curious fact of low, though substantial, positive correlation of water to protein (W/P) ratio with two negatively correlated rheological parameters: plasticity and elasticity. The high correlation of water to protein contents ratio (W/P) with the thermal treatment temperature (T) may be explained with the relatively high

Table 1. Correlation coefficients between rheological parameters and chemical formulation and thermal treatment conditions

Parameters								
	Rheological state		Thermal treatment		Chemical formulation			Integrated thermal treatment
–	E	F	T	t	RFC	W/B	PM	L_{75} t
P	–0.676***	–0.757***	–0.684***	0.071	–0.412***	0.201*	0.176*	–0.795***
E	–	0.879***	0.178*	0.210*	0.710***	0.200*	0.313***	0.457***
F		–	0.333***	0.035	0.640***	0.049	–0.311***	0.457***
T			–	–0.599***	–0.051	–0.470***	0.139	
t				–	0.013	0.249**	–0.113	
RFC					–	0.306***	–0.346***	
W/B						–	–0.019	

Significance level: *** = P ≤ 0.001, ** = P ≤ 0.01, * = P ≤ 0.05.

thermal losses reducing water content in the product in the variants heated to the highest temperatures. On the other hand, in the variants representing products with high fat content and addition of polyphosphates, big mass losses could mean fat melting and not water loss. The distribution of thermal losses in the model products is presented in the Figure 1. As it may be seen, in the majority of cases no losses were observed. The higher losses were observed in the variants of high fat content heated to high temperatures. The possibility of co-existence of many types of such interactions forced us to interpret the experimental results in a systematic way, basing on multifactor correlation analysis.

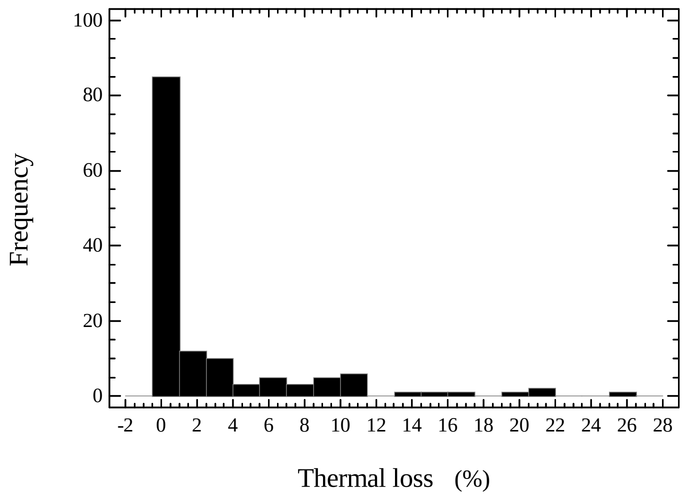

Fig. 1. Frequency distribution of thermal loss from model products

The concept of systematic data analysis and an attempt at uniform description of the observed relations

It was assumed that each parameter characterising the rheological properties of experimental subjects N_i may be described with the sum of elements dependent on the parameters characterising their raw material composition and production process conditions. Such an assumption enabled the use of convenient analysis of correlation and multiple regressions. Having in mind that not all the parameters characterising raw materials and production process would have the character of independent variables and that certain relations, by their nature, have a non-linear character, the necessity of making necessary parameter integration, of line arising of curvilinear relations and of taking into consideration the possible interaction between the examined factors, was assumed.

Integration of thermal treatment parameters

The integration of the thermal treatment parameters was based on the principles applied by Ball and Olson [1] for the integration of these parameters in the examination of their influence on microflora reduction. Therefore, it was assumed that the model temperature was 250°F (121.1°C) and the empirical formula of lethality L_z was been applied:

$$L_z = \log^{-1}\frac{T - 250^o F}{Z} \tag{1}$$

where (T) means the thermal treatment temperature, and the parameter (Z) determined in °F is the measure of thermal susceptibility of the subject to the action of temperature (similar to the thermal resistance of microorganisms). Such a transformation of the sterilisation temperature was useful while describing the dependence of the parameters of beef meat texture on sterilisation temperature of the canned beef stew [8]. On the basis of the specific tests [11] it was found that the best conformity of results was obtained for Z = 75°F (42°C) and, therefore, it was assumed that the integrated parameter of thermal treatment would be the product of lethality (L_z) and time (t) of keeping the subject in a given temperature and that the dependence of the parameters of the rheologic state of the tested subjects N_i on this parameter would be possible according to the formula:

$$N_i = \mathrm{A} + \mathrm{B}\,(L_{75}\cdot t) \tag{2}$$

The positive result of the integration of parameters of thermal treatment has been shown in the form of substantially higher correlation coefficients, as given in the Table 1.

Integration of thermal treatment and real fat content (RFC) parameters

Having regard to the border conditions of the effects, one should provide for the possibility of interaction between the factors characterising raw material composition and thermal treatment parameters.

As it results from the Table 1, the rheological parameters: elasticity (E) and fluidity (F) depend, first of all, on fat content in the stuffing. On one hand we can imagine a very lean stuffing, practically with no fat (RFC = 0), on the other hand – a very fatty stuffing. In the first case there is no relation of the thermal treatment parameters with the fat content, in the second case, however, at high temperatures and long time of thermal treatment, fat may melt down and the block will contain less fat than it results from the raw material recipe. The melting down of fat was observed at the highest sterilisation temperature of 129.1°C. In the Figure 2 the distribution of the fat content in model products has been presented. Therefore, it could be envisaged that while examining the relation of rheological parameters, the equation of the type as follows would be taken into consideration:

$$N_i = A_i(T_{75}\cdot t)+B_i\cdot RFC+C_i\cdot RFC\cdot(T_{75}\cdot t)+D_i \qquad (3),$$

where: N_i – examined rheological parameter, and A_i, B_i, C_i, D_i, constants. The interaction effect will appear depending on the value and sign of the constant "C_i". If it is positive, it would mean the strengthening of the effect of thermal treatment at the increase of fat content in the stuffing, if negative – it would mean the weakening of this effect. $C_i = 0$ shall mean no interaction.

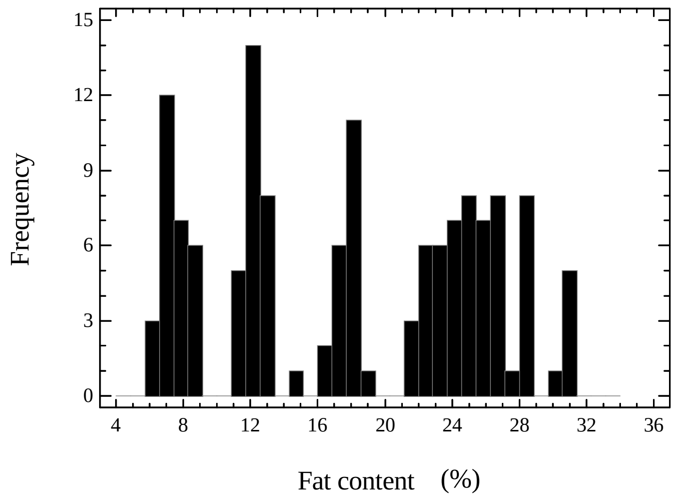

Fig. 2. Frequency distribution of fat content in model products

Transformation of the parameter connected with phosphorus (PM) content

In the Figure 3 the distribution of phosphorus content in the model products has been presented.

As we know, the addition of polyphosphates to the stuffing results in better water binding ability, less ability of thermal loss, and improvement of block texture. These effects, however, do not increase in a linear way, following the increase of phosphorus content in the stuffing. Above a certain limit of phosphorus addition, no more effects were observed [10]. A certain volume of natural phosphorus is contained in the meat itself, and – more precisely – in its lean muscle tissue. In the equation describing the relation of the stuffing rheological parameters it was provided that the effect would be curvilinear and – in order to make the effect linear – an inverse of phosphorus content in a block would be applied. In this connection, in the equations of elasticity N_2 = E and fluidity N_3 = P parameters, the relation of the type as below will be provided for:

$$N_i = A_i + B_i \cdot \frac{1}{PM} \qquad (4),$$

and in the case of plasticity (*P*), showing positive correlation, the relation will be as follows:

$$N_1 = P = S_{(PM)} = A \cdot \frac{1}{B + \frac{C}{PM}} \qquad (5).$$

In both the cases, if the value “PM” grows to infinity, the effect of polyphosphates will be limited with the constant value $N_i = A_i$ or P = A/B.

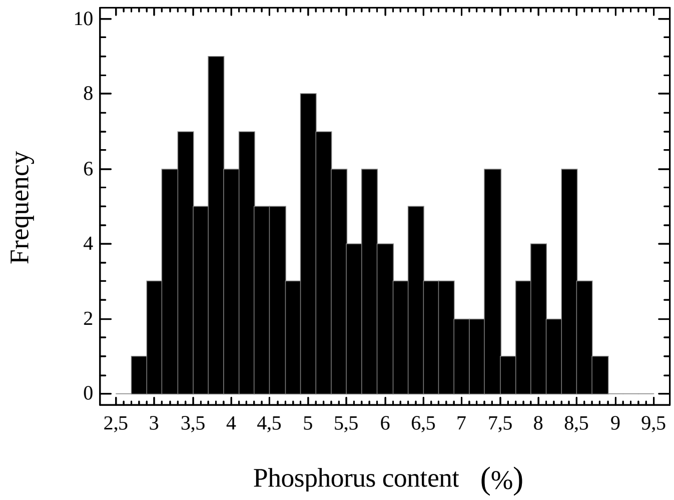

Fig. 3. Frequency distribution of phosphorus content in model products

The role of the protein hydration coefficient (W/P) in the shaping of the product rheological parameters

In the Figure 4 the distribution of the ratio of water content (W) to protein content (P) in model products has been presented. The protein hydration coefficient, being the ratio of water content to protein content in the meat, is a non-denominated Feder number characteristic for particular muscles or groups of muscles of slaughter animals and it is directly connected with the efficiency (productivity) of the products. By principle, for block meat products, it is determined on a constant level, guaranteeing no or a minimum of thermal loss only. In our case, at the constant level of water addition to the stuffing and at the assumed high variation of fat content and possibility of thermal loss, the said coefficient was showing its dependence on all other variable factors. Thus a simple addition of the element dependent on the protein hydration coefficient to other variable factors has been assumed. The stated relations between the parameters characterising the rheological properties of model products proved to be specific for products of high protein content (positive correlation between elasticity (E) and fluidity (F) [7].

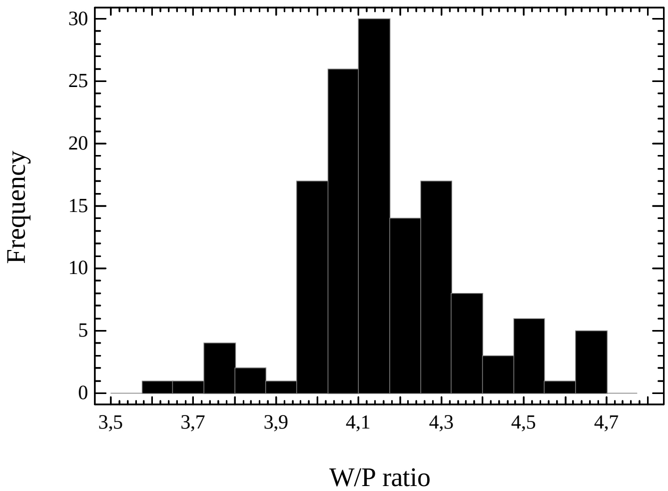

Fig. 4. Frequency distribution of W/P ratio in model product

Factors affecting plasticity of block cured meat

The analysis of multiple correlations and multiple linear regressions has shown that all the examined factors have substantial influence on plasticity (P) and the equation:

$N_1 = P = \Sigma P_j$ takes the form:

$$P = 2.99 - 0.052\, L_{75}\cdot t - RFC(0.103 - 0.0012\, L_{75}\, x\cdot t) - 0.951\frac{1}{0.179 + 0.086\frac{1}{PM}} - 0.440\, W/P \qquad (6).$$

The multiple correlation coefficient is 0.959.

In the Figure 5 a graphic relation between the observed values and those predicted from the equation has been presented. For edge variants: without phosphate additives, PM = 3.2 g kg^{-1} P_2O_5, $S_{(PM)}$ = 4.85g kg^{-1} P_2O_5, with big phosphates additive PM $\rightarrow\infty$ $S_{(PM)}$ = 5.59 g $kg^{-1}P_2O_5$. For lean meat without fat (RFC = 0) without phosphates addition $S_{(PM)}$ = 4.85g $kg^{-1}P_2O_5$ and at Feder number W/P = 4 the equation (6) is simplified to the form:

$$P = 6.08 - 0.052\, L_{75}{\cdot}t \qquad (7).$$

In the figure 6 this equation has been drafted (straight line 1) and its run has been shown: for fat content of 20% (straight line 2), for increased value of the coefficient W/P = 5 (straight line 3) and addition of polyphosphates at the level of 6.7 g kg^{-1} (straight line 4).

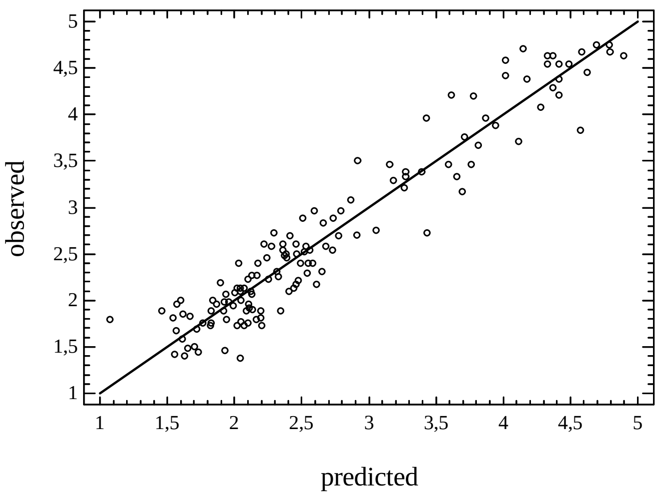

Fig. 5. Plot of Plasticity

Factors affecting elasticity (E) of block cured meat

The analysis of multiple correlations and multiple linear regressions has shown that the interaction between the parameters of thermal treatment and fat content is not important for elasticity (E) and the equation:

$$N_2 = E = \Sigma E_j \qquad \text{takes the form:}$$

$$E = -5.911 + 0.027\, L_{75}{\cdot}t + 0.128\, RFC + 4.50\, \frac{1}{PM} - 2.07\, W/P \qquad (8)$$

The multiple correlation coefficient is 0.821. In the Figure 7 a graphic relation between the observed values and those predicted from the equation has been presented. For edge variants: without phosphates addition PM = 3.2 g kg^{-1} P_2O_5 and for Feder number = 4 the equation (8) is simplified to the form:

$$E = 3.78 + 0.027\ L_{75}{\cdot}t + 0.128\ RFC \qquad (9)$$

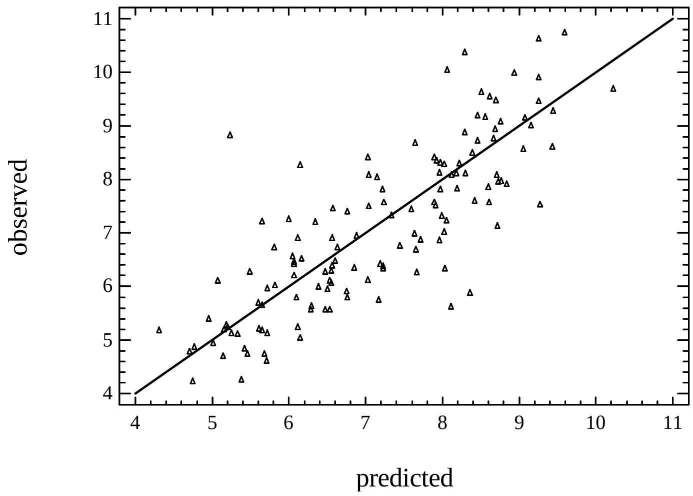

Fig. 7. Plot of Elasticity

Factors affecting fluidity (F) of block cured meat

The analysis of multiple correlations and multiple linear regressions has shown that the interaction between the parameters of thermal treatment and fat content is not important for fluidity (E) and the equation:

$N_3 = F = \Sigma F_j$ takes the form:

$$F = -2.621 + 0.015\ L_{75}{\cdot}t + 0.054\ RFC + 2.663\frac{1}{PM} + 0.576\ W/B \qquad (10).$$

The multiple correlation coefficient is 0.822. In the Figure 8 a graphic relation between the observed values and those predicted from the equation has been presented. For edge variants: without phosphates addition (PM = 3.2 g kg^{-1} P_2O_5) and for Feder number = 4 the equation is simplified to the form:

$$F = 0.515 + 0.015\ L_{75}{\cdot}\ t + 0.054\ RFC \qquad (11)$$

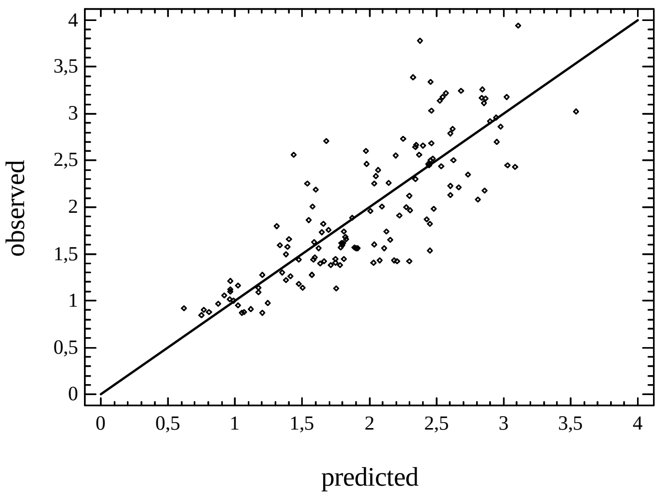

Fig. 8 Plot of Fluidity

CONCLUSIONS

1. The influence of the conditions of thermal treatment, fat content and protein hydration as well as polyphosphate addition on the rheological state of the model block cured meat type, characterised with CASRA analysis parameters, i.e. plasticity (*P*), elasticity (*E*) and fluidity (*F*) has been tested on an extensive and diversified trial material.

2. It has been found and stated that:

- the conditions of the thermal treatment affect mostly the plasticity (*P*) – the most important parameter from the point of view of a food technician, determining the product block behaviour during slicing,
- the fat content affects all the examined rheological parameters, but mostly the elasticity (*E*) and fluidity (*F*),
- the protein hydration affects the plasticity (P) and elasticity (*E*).
- the addition of polyphosphates affects mostly the elasticity (*E*) and fluidity (*F*).

3. We have succeeded in integrating effectively the conditions of thermal treatment, i.e. temperature and time of heating, basing on the Ball-Olson concept applicable to the integration of the thermal sterilisation conditions of micro-organisms in tinned products. The time of keeping the outer parts of the block in high temperature has been taken as the time of heating.

4. With an excellent accuracy the relation of plasticity (P) on all the examined factors has been described, having regard to the interactions between the thermal treatment conditions and fat content in the product stuffing.

5. With a good accuracy the relation of elasticity (E) and fluidity (F) on all the examined factors has been described. The statistical analysis has shown no important interaction between the thermal treatment conditions and fat content in the tinned product stuffing. One cannot exclude that it is possible to achieve better accuracy of the description of the relation, if the curvilinear character of the examined relations and possible importance of other interactions between the examined factors are taken into consideration, as well as more factors like meat water absorption and pH value.

6. A systematic, relatively simple chemometric proceeding has been presented, enabling prediction of quality features of meat products.

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PROGNOZOWANIE REOLOGII ŻYWNOŚCI. CZYNNIKI KSZTAŁTUJĄCE WŁAŚCIWOŚCI REOLOGICZNE WĘDLIN BLOKOWYCH

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S t r e s z c z e n i e . Na licznym i zróżnicowanym materiale badawczym przebadano wpływ warunków obróbki cieplnej, zawartości tłuszczu i uwodnienia białek oraz dodatku wielofosforanów na stan reologiczny modelowej wędliny blokowej typu „luncheon meat" charakteryzowanej parametrami analizy CASRA, tj . plastyczności (P), elastyczności (E) i płynności (F). Stwierdzono, że: warunki obróbki cieplnej najsilniej oddziaływają na plastyczność (P) – najważniejszy z punktu widzenia technologa żywności parametr decydujący o zachowaniu się bloku produktu w czasie plasterkowania, zawartość tłuszczu oddziałuje na wszystkie badane parametry reologiczne, ale najsilniej na elastyczność (E) i płynność (F), uwodnienie białka oddziałuję na plastyczność (P) i elastyczność (E), a dodatek wielofosforanów najsilniej oddziałuję na elastyczność (E) i płynność (F). Udało się skutecznie zintegrować warunki obróbki cieplnej tj. temperaturę i czas ogrzewania w oparciu o koncepcję Balla-Olsona stosowaną do integracji warunków sterylizacji cieplnej drobnoustrojów w konserwach. Jako czas ogrzewania przyjęto czas przebywania w wysokiej temperaturze zewnętrznych partii bloku. Z bardzo dobrą dokładnością opisano zależność plastyczności (P) od wszystkich badanych czynników, przy uwzględnieniu zachodzących interakcji między warunkami obróbki cieplnej a zawartością tłuszczu w farszu produktu. Z dobrą dokładnością opisano zależność elastyczności (E) i płynności (F) od wszystkich badanych czynników. Analiza statystyczna wykazała brak istotności interakcji między warunkami obróbki cieplnej i zawartością tłuszczu w farszu konserwy. Zademonstrowano systemowe, stosunkowo proste chemometryczne postępowanie umożliwiające prognozowanie cech jakościowych produktów mięsnych.

S ł o w a k l u c z o w e : mięsne produkty blokowe, właściwości reologiczne, prognozowanie reologii żywności, warunki obróbki termicznej