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ANALYSIS OF THE IMPACT OF CLIMATE FACTORS ON THE LEVEL OF MECHANICAL PARAMETERS OF SELECTED PACKAGING FILMS USED FOR FOOD PRODUCTS

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Key words: climate factors, functional value of packaging films, food product packaging.

Abstract

Plastic films are of key importance as a group of materials used for packaging food products. It is therefore crucial that they meet specific functional and durability requirements as well as comply with all regulations regarding food contact materials. A degree to which a set of properties of these materials satisfies the requirements connected with their usage determines their functional value. The level of functional value depends to a large extent on climate factors affecting these materials in the post-production stage.

The aim of this work was to analyze the effect of climate factors on the level of changes of the parameters characterizing the functional value of polyolefin packaging films used for food products.

The research was conducted with the main focus on the scope and intensity of changes of selected properties of packaging films in different microclimate conditions. The results became the basis of assessing the impact of climate factors on the level of changes of the parameters characterizing functional value and served as a groundwork to the analysis of the correlation between the changes in the parameters and the level of functional value of the plastic films.

ANALIZA WPŁYWU CZYNNIKÓW KLIMATYCZNYCH NA POZIOM ZMIAN PARAMETRÓW CHARAKTERYZUJĄCYCH WARTOŚĆ UŻYTKOWĄ FOLII OPAKOWANIOWYCH Z TWORZYW SZTUCZNYCH PRZEZNACZONYCH DO PAKOWANIA PRODUKTÓW SPOŻYWCZYCH

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Abstrakt

Folie z tworzyw sztucznych stanowią ważną grupę materiałów wykorzystywanych w opakowalnictwie do pakowania m.in. produktów spożywczych. W związku z czym muszą spełniać określone wymagania wytrzymałościowe oraz wymagania stawiane materiałom przeznaczonym do kontaktu z żywnością. Stopień spełnienia przez materiały stawianych im wymagań z punktu widzenia ich przeznaczenia wyznacza ich wartość użytkową. Poziom wartości użytkowej folii jest zdeterminowany w dużym stopniu wpływem czynników klimatycznych, które oddziałują na te materiały w sferze poprodukcyjnej.

Celem pracy jest analiza wpływu czynników klimatycznych na poziom zmian parametrów charakteryzujących wartość użytkową folii opakowaniowych z tworzyw sztucznych przeznaczonych do pakowania produktów spożywczych.

Introduction

Plastic films belong to one of the most important groups of materials used for packaging. Polyolefin films dominate in this group with the market share of 90%. This kind of films is widely used in several different industries with a particular emphasis on food production performed with the use of filling and packaging machines. Because of that, polyolefin films have to meet specific functional and durability requirements as well as comply with all regulations regarding food contact materials (LISIŃSKA-KUŚNIERZ and KAWECKA 2012, LISIŃSKA-KUŚNIERZ and CHOLEWA-WÓJCIK 2012). A degree to which a set of properties of these materials satisfies the requirements connected with their usage determines their functional value. A required level of the packaging film's functional value can be achieved by a proper selection of production methods, extrusion parameters as well as the raw materials used. However, all the activities leading to attaining that level cannot merely focus on the production stage. Packaging films are subject to aging processes as a result of which irreversible changes in their properties take place, which in turn affects the overall functional value of the films. The level of functional value depends to a large extent on climate factors affecting these materials in the post-production stage. That is why, in order to create a stable level of functional value of packaging films it is important to ensure proper storage conditions of the films before the packaging processes take place, and then of the food products packed in them (CHOLEWA-WÓJCIK 2011). The aim of this work was to analyze the effect of climate factors on the level of changes of the parameters characterizing the functional value of polyolefin packaging films used for food products.

Materials and Methods

The empirical studies focused on polyolefin films manufactured in Poland. Five different types of films were selected, among which homogenous films as well as the ones produced from two kinds of polyolefin and those with extra minerals added, such as chalk or talc, could be found. Generic presentation of research material is shown in Table 1.

Table 1

Presentation of research material

Type of polyolefin film	Trade name	Producer
Multilayer film OPP	Bifol BG	Flexpol
Coextruded laminate OPP-PE	Biaxfol	Folmar
Multilayer film PE (LLDPE)	Politerm TB	TB Opakowania
Multilayer film PE+PP	Cristel	Plasticos
Multilayer film with minerals	Ecor FPO WRAP	Ecor

The destructive impact of the temperature, solar radiation and relative humidity on polyolefin films was analyzed in several microclimate condition variants. The films were stored for a period of 12 months.

Variant I – stable microclimate conditions with the following parameters: T = 20±1°C, RH = 65±2% (normal atmospheric research conditions according to EN-ISO 554:1996).

Variant II – stable microclimate conditions with the following parameters: T = 40±1°C, RH = 65±2% (the temperature is 20°C higher in relation to the normal conditions with the relative air humidity as given above).

Variant II bis – stable microclimate conditions with the following parameters: T = 40±1°C, RH = 65±2% with optional xenon lamp irradiation at a dose of 50 MJ m^{-2}.

Variant III – stable microclimate conditions with the following parameters: T = 20±1°C, RH = 90±2% (the temperature on a normal conditions level with the relative air humidity on a dramatically high level).

Variant IV – stable microclimate conditions with the following parameters:

T = -20±1°C, RH = 40±2% (the conditions include the usage of films for packing deep-frozen products).

Variant V – changeable microclimate conditions with the following parameters 10±1°C < T < 22±1°C and 56±2% < RH < 64±2% (monitored in the warehouse of the packaging film manufacturer without the possibility of regulating the conditions of the surrounding environment.

Empirical research program to assess the impact of climatic factors on changes in the value in use of polyolefin packaging film during aging are shown in Table 2.

Table 2
Empirical research program to assess the impact of climatic factors on the value in use of packaging film

Microclimate parameter affectingon film properties	Microclimate condition variant	Test cycle (month)	Research time (month)
Tempeture (T) T = 20°C, 40°C and RH = 65% T = -20°C and RH= 40%	I, II, IV	1	12
		4	
UV radiation and temperature (T) T = 40°C I RH= 65%	II BIS	–	0,25–1*
Humidity (RH) RH = 65% and 90% and T = 20°C	I, III	1	12
Temperature and humidity fluctuations 10±1°C < T < 2 2±1°C 56±2% < RH < 64±2%	V	1	

Results and Discussion

In order to verify the hypothesis of the materiality of the impact of climate factors (temperature, humidity and UV radiation) on changes in mechanical parameters affecting the polyolefin films' functional value, a one-factor analysis of variance was performed with the use of ANOVA. The basis of this analysis was formed by the values of parameters of break load and elongation of all tested films, previously stored in different variants (I–V) of microclimate conditions at different temperature and humidity levels as well as with a xenon lamp irradiation option (variant II bis). Two research hypotheses were formed for the sake of the analysis. According to the null hypothesis, microclimate conditions do not differentiate the average levels of value of analyzed parameter. The alternative hypothesis suggests that there are vital differences between average values of parameters depending on different microclimate conditions. In order to accept or reject the zero hypothesis, an F-statistics method (or F-test) was used. If the final value of F-statistics calculated based on the tests will fall within the critical set, the tested hypothesis has to be rejected and the alternative one accepted. If, however, the value of F-statistics will be outside the critical set, there is no reason to reject the null hypothesis. The level of significance was set on $\alpha = 0{,}05$ (the probability of rejecting the null hypothesis). Selected results of the analysis of the impact of climatic factors on the level of changes of parameters affecting the plastic films' functional value are presented in Table 3.

The one-factor variance analysis revealed a relevant impact of microclimate conditions on the level of parameters characterizing functional value of all tested polyolefin films. The probability test was lower than 0.05 in all plastic

Table 3

Selected results of the analysis of the impact of climate factors on the level of changes of parameters affecting the plastic films' functional value after 12 months of storage

Plastic film type	Parameter	Direction	Average value						F Statistics	Value p
			microclimate condition variant							
			I	II	III	IV	V	II BIS		
Biaxfol	break load P (N)	along	20.494	17.599	20.365	22.017	20.406	4.502	105.636	0.000
	elongation W (%)		32.161	29.951	32.067	38.071	32.118	5.143	77.645	0.000
	break load P (N)	across	21.937	20.074	21.751	23.518	21.629	x	46.631	0.000
	elongation W (%)		24.515	21.061	24.594	27.794	23.902	x	60.259	0.000
Cristel	break load P (N)	along	18.591	17.634	18.426	19.095	18.513	0.308	11.248	0.000
	elongation W (%)		47.676	46.706	48.029	51.409	48.445	8.588	16.504	0.0 00
	break load P (N)	across	20.718	18.272	20.622	21.556	20.592	x	48.144	0.000
	elongation W (%)		41.136	40.095	40.951	42.391	40.947	x	13.062	0.000
BG	break load P (N)	along	29.463	27.222	28.935	20.656	29.366	0.453	220.911	0.000
	elongation W [%]		48.650	42.912	47.742	37.081	47.729	3.773	84.472	0.000
	break load P (N)	across	50.001	41.941	49.297	23.746	49.886	x	495.887	0.000
	elongation W [%]		11.908	8.863	10.798	35.299	11.478	x	240.489	0.000
TB	break load P (N)	along	19.732	17.145	19.592	20.656	19.689	4.031	69.368	0.000
	elongation W [%]		39.360	34.578	38.855	37.081	39.030	4.897	8.131	0.000
	break load P (N)	across	21.121	19.689	20.502	23.746	21.049	x	148.501	0.000
	elongation W [%]		36.410	33.695	35.512	35.299	35.683	x	14.385	0.000
Ecor	break load P (N)	along	13.717	12.812	12.960	19.095	13.118	3.361	700.133	0.000
	elongation W [%]		443.113	120.066	205.189	51.409	453.238	7.076	1.564	0.182
	break load P (N)	across	22.986	22.216	22.848	21.556	23.103	x	36.649	0.000
	elongation W [%]		108.280	99.257	113.242	42.391	113.940	x	327.647	0.000

x – no results for different variants of microclimate conditions, resulting from the research program films that were analyzed. The only exception there was ECOR plastic film; the variance analysis of elongation along the length did not reveal any substantial differences in connection with storage conditions variant. The results of the analysis show a significant statistical difference between the values obtained in various variants of microclimate conditions. The impact of different microclimate conditions on the scope of changes in break load (*P*) and elongation (*W*) during storage in time period t = 12 months in different climate variants is presented in Figures 1–2.

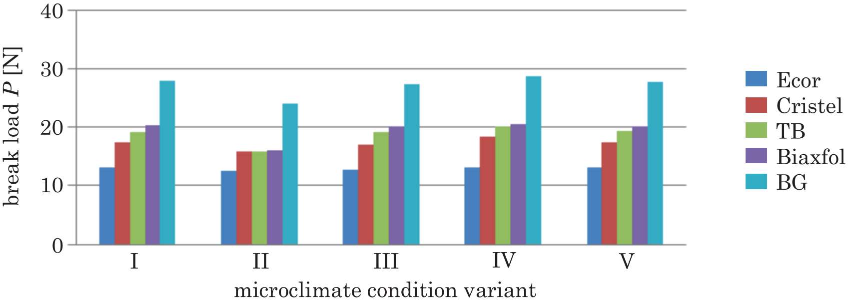

Fig. 1. The impact of different microclimate conditions on the scope of changes in break load (*P*) during storage in time period t = 12 months in different climate variants

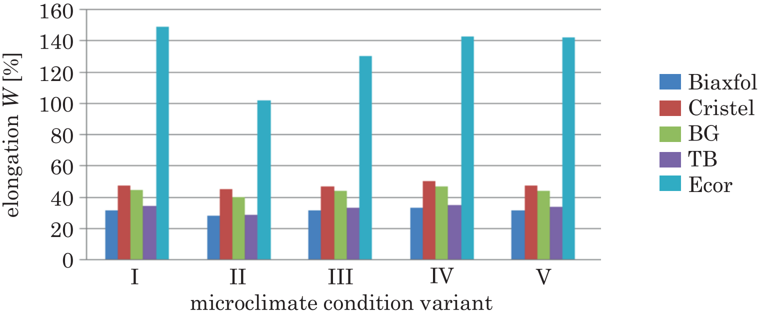

Fig. 2. The impact of different microclimate conditions on the scope of changes in elongation (*W*) during storage in time period t = 12 months in different climate variants

Based on the analysis of the impact of different microclimate conditions on the scope of changes in mechanical properties during storage it can be said that both the scope and dynamics of changes are much greater in case of elongation than in case of break load. This, of course, means that elongation is a parameter strongly responsive to the processes of thermal degradation.

Due to the fact that the variance analysis showed significant differences in values of mechanical parameters of the plastic films stored in five microclimate variants, it was necessary to use post hoc tests. Further analysis was performed with the application of Tukey's HSD test (Honestly Significant Difference test) with the aim to point out the most significant differences in average values of mechanical parameters. The results of the HSD test enabled us to determine the microclimate condition variant pairs which do not much modify the parameters characterizing mechanical properties. The obtained results are presented in Table 4.

Table 4

Tukey's HSD test results

Film's parameter	Direction	Plastic film type				
		Biaxfol	Cristel	BG	TB	Ecor
Break load *(P)*	along	I–III I–V	I–III I–V III–V	I–III I–V III–V	I–III I–V III–V	II–III II–V III–V
	across	I–III I–V	I–III I–V	I–V	I–V	I–III I–V III–V
Elongation *(W)*	along	I–III I–V III–V	I–III I–V III–V II–III	I–III I–V III–V	I–III I–IV I–V	
	across	I–III I–V III–V	I–III I–V III–V II–V	I–III I–V III–V	I–III I–V III–V	I–III I–V III–V

I, II etc. – microclimate condition variants

The analysis of obtained results, which are consistent with the research carried out by Bielinski, Schael, Serge, Laurent among others, became the basis of the evaluation of the impact of analyzed parameters on the level of changes in functional properties of polyolefin films (BIELIŃSKI 2006, SCHAEL 2003, SERGE and LAURENT 2002).

The rates of dynamics of degradation presented in Tables 5–6 and a calculated average period of the speed of changes in the long-term storage in two microclimate conditions variants became the basis of one-factor variance analysis. The aim of this analysis was to verify the hypothesis on the possibility of determining the critical boundary property[1]. In the variance analysis two hypotheses were formed. According to null hypothesis, the parameters characterizing mechanical properties and structural changes do not present any significant changes in average-term values during long-term storage. The alternative hypothesis is based on the assumption that there are significant

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[1] Critical boundary property is a property in the set of critical characteristics which is the first to cease to meet the requirements related to functional value (PN-ISO 6707-1:2008).

changes in dynamics between analyzed parameters that have an impact on the average-term speed of changes which can be determined by the critical boundary property. In order to decide which of the two hypotheses should be accepted, the method of *F*-statistics was used. If the value of *F*-statistics calculated based on the tests will fall within the critical set, the tested hypothesis has to be rejected and the alternative one accepted. If, however, the value of *F* statistics will be outside the critical set, there is no reason to reject the null hypothesis. The level of significance was set on $\alpha = 0.05$ (the probability of rejecting the null hypothesis).

Table 5

The rate of dynamics of changes of critical properties' parameters and the average-term speed of decline during long-term storage in microclimate conditions variant I [%]

Type of film	Parameter	Direction	Cycle of research (4 months)				Average-term speed of changes [%]
			0	4	8	12	
Biaxfol	break load *P*	along	100	99.3	99	98.4	-0.5
		across	100	101	95	94.1	-2.0
	elongation *W*	along	100	97.3	95	94.1	-2.0
		across	100	103	95	92.8	-2.5
	molecular weight		100	86.4	77	71.8	-10.5
Cristel	break load *P*	along	100	100	94	91.8	-2.8
		across	100	93.9	93	92.2	-2.7
	elongation *W*	along	100	102	101	99.9	0.0
		across	100	101	99	98.3	-0.6
	molecular weight		100	83.9	75	69.1	-11.6
BG	break load *P*	along	100	95.3	88	87.2	-4.5
		across	100	91.3	75	73.5	-9.8
	elongation *W*	along	100	87.9	79	78.8	-7.6
		across	100	89.1	69	68.4	-11.9
	molecular weight		100	94.4	57	33.3	-30.7
TB	break load *P*	along	100	98.5	96	95.6	-1.5
		across	100	93.9	93	92.5	-2.6
	elongation *W*	along	100	94.4	82	81.2	-6.7
		across	100	103	99	96.9	-1.0
	molecular weight		100	81.9	69	66.5	-12.7
Ecor	break load *P*	along	100	97.1	101	99.8	-0.1
		across	100	98.4	97	95.8	-1.4
	elongation *W*	along	100	103	80	56.9	-17.1
		across	100	93.3	72	70	-11.2
	molecular weight		100	92.9	78	73.3	-9.8

Table 6

The rate of dynamics of changes of critical properties' parameters and the average-term speed of decline during long-term storage in microclimate conditions variant II [%]

Type of film	Parameter	Direction	Cycle of research (4 months)				Average-term speed of changes [%]
			0	4	8	12	
Biaxfol	break load *P*	along	100	85.3	82	77.9	-8.0
		across	100	93.4	83	81.2	-6.7
	elongation *W*	along	100	90.4	87	83.8	-5.7
		across	100	84.9	79	76.9	-8.4
	molecular weight		100	82.7	73	67.1	-12.5
Cristel	break load *P*	along	100	96.3	89	83.2	-5.9
		across	100	83.4	78	77.2	-8.3
	elongation *W*	along	100	100	97	95.1	-1.7
		across	100	98.9	97	94.4	-1.9
	molecular weight		100	75.5	71	61.7	-14.9
BG	break load *P*	along	100	91.3	82	75.3	-9.0
		across	100	67.8	65	63.5	-14.0
	elongation *W*	along	100	72.1	71	70.3	-11.1
		across	100	70	46	44.3	-23.8
	molecular weight		100	71.6	30	22.8	-38.9
TB	break load *P*	along	100	85.2	79	79.1	-7.5
		across	100	88.4	86	83.2	-5.9
	elongation *W*	along	100	96.4	93	87.2	-4.5
		across	100	80.4	70	68.5	-11.8
	molecular weight		100	68.6	67	59.4	-15.9
Ecor	break load *P*	along	100	96.2	96	95.2	-1.6
		across	100	95.9	92	91.6	-2.9
	elongation *W*	along	100	49.6	41	38.9	-27.0
		across	100	86.3	65	60.4	-15.5
	molecular weight		100	89.1	77	68.8	-11.7

The analysis of obtained results allows to draw a conclusion that there are statistically significant differences in the dynamics of changes in tested parameters. Based on the interpretation of the intensity of changes of those parameters as well as the average-term speed of decline, a molecular weight was observed to be the critical parameter. This result is supported by the research results of several authors, such as DOBKOWSKI (2006), BUDTOV et al. (2003), SCARFATO et al. (2002). They believe that, the consequence of aging as a result of the mechanism of thermal or photo oxidation is the fact that the first changes appear in the structure of the polymers. The further effect of

Table 7

A correlation of the impact of molecular weight on the changes in mechanical properties of polyolefin films stored in microclimate conditions variant I and II

Type of film	Parametr	Direction	Regression model for variant I $\overline{M_w} = f(P)$; $\overline{M_w} = f(W)$	Regression model for variant II $\overline{M_w} = f(P)$; $\overline{M_w} = f(W)$
Biaxfol	break load P	along	$\overline{M_w} = 19{,}5217 + 0{,}004P$	$\overline{M_w} = 6{,}7986 + 0{,}0468P$
		across	$\overline{M_w} = 17{,}5959 + 0{,}0179P$	$\overline{M_w} = 9{,}2356 + 0{,}0462P$
	elongation W	along	$\overline{M_w} = 26{,}5353 + 0{,}0234W$	$\overline{M_w} = 17{,}0416 + 0{,}0555W$
		across	$\overline{M_w} = 18{,}7697 + 0{,}0242\ W$	$\overline{M_w} = 18{,}7697 + 0{,}0242W$
Cristel	break load P	along	$\overline{M_w} = 14{,}0906 + 0{,}0151\ P$	$\overline{M_w} = 11{,}5764 + 0{,}022\ P$
		across	$\overline{M_w} = 16{,}1161 + 0{,}0163\ P$	$\overline{M_w} = 7{,}7787 + 0{,}0401P$
	elongation W	along	$\overline{M_w} = 47{,}8923 - 0{,}0009W$	$\overline{M_w} = 42{,}2957 + 0{,}0154W$
		across	$\overline{M_w} = 6{,}8742{+}0{,}0623W$	$\overline{M_w} = 39{,}0874 + 0{,}0059W$
BG	break load P	along	$\overline{M_w} = 26{,}6571 + 0{,}0173P$	$\overline{M_w} = 20{,}2426 + 0{,}0352P$
		across	$\overline{M_w} = 39{,}5647 + 0{,}0705P$	$\overline{M_w} = 28{,}6137 + 0{,}0757P$
	elongation W	along	$\overline{M_w} = 40{,}6372 + 0{,}0508W$	$\overline{M_w} = 32{,}6285 + 0{,}0559W$
		across	$\overline{M_w} = 35{,}8417{+}0{,}0153W$	$\overline{M_w} = 8{,}5586 + 0{,}0209W$
TB	break load P	along	$\overline{M_w} = 17{,}6299 + 0{,}0062P$	$\overline{M_w} = 20{,}2426 + 0{,}0352P$
		across	$\overline{M_w} = 17{,}4018 + 0{,}0117P$	$\overline{M_w} = 13{,}2864 + 0{,}022P$
	elongation W	along	$\overline{M_w} = 18{,}0042 + 0{,}0592W$	$\overline{M_w} = 12{,}7647 + 0{,}072W$
		across	$\overline{M_w} =1{,}9576 + 0{,}0358W$	$\overline{M_w} = 32{,}8187 + 0{,}0077W$
Ecor	break load P	along	$\overline{M_w} = 13{,}7 - 0{,}0009P$	$\overline{M_w} = 20{,}2426 + 0{,}0352P$
		across	$\overline{M_w} = 20{,}3805 + 0{,}004P$	$\overline{M_w} = 16{,}9309 + 0{,}0082P$
	elongation W	along	$\overline{M_w} = -126{,}4102 + 0{,}503\ W$	$\overline{M_w} = -251{,}8698 + 0{,}5971W$
		across	$\overline{M_w} = -46{,}8838 + 0{,}231W$	$\overline{M_w} = -26{,}3672 + 0{,}2068W$

structural changes in polymer's macromolecules is a break in the chain which leads to a decrease in molecular weight. That is why the molecular weight can be considered as a critical parameter and it can be thus concluded that the changes leading towards the loss in original functional properties of the product are initiated there. According to the research results of BIELIŃSKI (2006), even a small share of reactions connected with a decrease in molecular weight (chain break) leads to a deterioration in mechanical properties. Based on data presented by e.g. GALOTTO et al. (2008) it is known that even the smallest changes in molecular weight have a negative effect on mechanical durability of polyolefin films. Considering all of the above and the correlation of structural changes with mechanical durability, the parameters determining mechanical durability can be treated as pointing towards degradation rates, and based on such knowledge all trade specifications are established. From the point of view of the practical business approach those parameters which determine mechanical properties are extremely useful in terms of analysis and interpretation of changes in functional properties.

The next stage of interpretation of empirical research results focused on the correlation analysis of the impact of critical parameter on the changes of all other tested parameters of polyolefin films' functional properties. A particular focus was put on the impact of the parameters characterizing structural changes on the level of changes of parameters describing mechanical properties. This was achieved by regression analysis, which was performed for all tested polyolefin films including variant I and II of microclimate conditions (different levels of temperature). In the correlation analysis, the explanatory variable (*Y*) was molecular weight (Mw) whereas dependent variable (*X*) was a break load (*P*) and elongation (*W*). The results of the analysis allowed to create models of regression which are presented in Tables 7.

Based on the models of regression presented in Tables 7 a reaction force of molecular weight changes with changes in break load and elongation at break can be determined. The reaction force can be calculated based on directional factor. With all this in mind, it is possible to state that regardless the microclimate conditions variant used, a change in molecular weight has the strongest impact on elongation. A decrease in molecular weight by 10 units leads to an elongation change, depending on the type of film, between 0,1–5% in case of variant I and 1–6% in case of variant II. The break load does not seem to have such a strong effect on the films with 0,09–1,8 N in variant I and 0,2–0,7 N in variant II.

Conclusions

The analysis of obtained results proves the thesis that microclimate conditions influence the level of changes of parameters characterizing functional value of packaging films. Moreover, the tests conducted on the impact of microclimate conditions on the scope and intensity of changes in properties of polyolefin films allowed us to point out these particular properties which have a significant effect on functional value. With this in mind, only such properties were later analyzed which are responsible for changes within the system: microclimate conditions – packaging material (plastic film). These properties were considered to be critical ones and among them we can find all those parameters that characterize structural changes of films and their mechanical durability, which entails that in practical terms such films will be used in highly efficient packaging machines and should keep the given form intact together with the food product they contain.

Although polyolefin films do not have to meet very specific requirements concerning the evaluation of their functional value and there are no research procedures to perform such evaluation, it is vital to constantly review the properties characterizing the usability and functionality of food contact materials during storage. This approach is supported by the *Systemy zarządzania...* PN-ISO 22000:2006 and is extremely important for businesses as a means of creating competitive edge.

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