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EVALUATION OF THE LAND USE STRUCTURE IN THE WARMIAN-MASURIAN VOIVODESHIP (POLAND) BASED ON VARIOUS CLASSIFICATION METHODS – CHANGES IN 2002–2012

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K e y w o r d s: agricultural landscape, municipalities, land use trends, ecosystem evaluation, cluster analysis.

A b s t r a c t

The article evaluates the land use structure in municipalities of the Warmian-Masurian voivodeship (Poland) in 2002–2012. The dynamics of changes in land use and the correlations between the components of the agricultural environment and land use structure were determined. The trends in land use and agricultural land management were identified, and agricultural and forest ecosystems were evaluated. Clusters of municipalities characterized by similar habitat conditions and land use were identified. The land use structure in the analyzed region was highly stable, and it was strongly correlated with the natural environment. A minor decrease in the percentage share of arable land, grassland and orchards was noted, and it was accompanied by an increase in forest cover in all municipalities. The forest cover in Warmia and Mazury exceeds the level planned for 2020. The applied classification methods produce highly similar results, and they point to clear regional variations in the natural and agricultural environment. The northern part of the region comprises mostly agricultural land, and it ranks lower with regard to its ecological importance. Agricultural acreage is also the predominant type of land use in the south-western part of the region despite poor quality soils. The southern and south-eastern parts of the region are also characterized by low quality soils, they feature a higher share of forests and grasslands which increase their ecological significance and raise their recreational appeal.

OCENA ZAGOSPODAROWANIA ZIEMI W WOJEWÓDZTWIE WARMIŃSKO-MAZURSKIM (POLSKA) ZA POMOCĄ RÓŻNYCH METOD KLASYFIKACJI – ZMIANY W LATACH 2002–2012

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S ł o w a k l u c z o w e: krajobraz rolniczy, gminy, kierunki użytkowania ziemi, waloryzacja ekologiczna ekosystemów, analiza skupień.

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Abstrakt

W artykule przedstawiono ocenę zagospodarowania ziemi w gminach województwa warmińsko-mazurskiego w latach 2002–2012. Oceniono dynamikę zmian w sposobach wykorzystania przestrzeni i zależności między elementami środowiska rolniczego a strukturą jego użytkowania, określono kierunki użytkowania ziemi i zagospodarowania użytków rolnych, dokonano przyrodniczej waloryzacji ekosystemów rolno-leśnych. Wyodrębniono skupienia gmin o podobnych warunkach siedliskowych i sposobach użytkowania gruntów. Struktura użytkowania ziemi w województwie wykazywała dużą stabilność i silną zależność od warunków przyrodniczych. Generalnie w regionie udział gruntów ornych, użytków zielonych i sadów nieznacznie się zmniejszył, ale we wszystkich gminach wzrosła lesistość. Aktualna lesistość województwa przekracza poziom zakładany na rok 2020. Zastosowane metody klasyfikacji wykazują dość dużą zbieżność i wskazują na wyraźne regionalne zróżnicowanie przyrodniczo-rolnicze. W pasie północnym województwa, przestrzeni o gorszych walorach ekologicznych, ale większej przydatności do celów rolniczych, dominuje takie właśnie zagospodarowanie. W części południowo-zachodniej podobnie dominuje użytkowanie rolnicze, mimo gorszej jakości gleb. Część południowa i południowo-wschodna, odznaczająca się również słabszymi glebami, jest silniej zalesiona i zadarniona, co podwyższa jej wycenę ekologiczną i staje się atutem rekreacyjnym.

Introduction

The agricultural landscape is a mosaic of agricultural land, forests and rural settlements. Meadows and pastures are also important elements of the agrarian environment, whereas orchards play a minor role in this system (STANIAK 2009). It is generally believed that agriculture and forestry are the key branches of the economy which are responsible for landscape protection and management. Rational spatial management policies should be based on quantitative evaluations of landscape quality and the condition of natural resources (KUNDROTAS 2002, KRASOWICZ et al. 2011). Land use structure should be synchronized with the natural and economic environment, subject to the sustenance and cultural needs of the local community (KUNDROTAS 2002, KOZOVÁ and FINKA 2010, SIUTA 2012). Changes in land use are inevitable and necessitated by urban development and the construction of transport networks (KRASOWICZ et al. 2011), but excessive anthropogenization leads to direct or indirect deformations of the natural landscape (*Planning of forestation*... 2002, SIUTA 2012). The loss of vast stretches of agricultural land and forests has a particularly devastating effect on ecosystem balance (VERBURG et al. 2009). For this reason, the course and dynamics of changes in land use should be monitored on a regular basis (ZANCHI et al. 2007, KRASOWICZ et al. 2011).

Land use analyses are one of the main tools supporting evaluations of the agricultural landscape (HARKOT et al. 2011). Poland has a well-established record of research into agricultural land use and changes in the agrarian environments, as demonstrated by numerous publications that discuss the issue on a regional and national basis. Land use analyses are conducted with the involvement of various mathematical methods, including multidimen-

sional statistical analyses (BAŃSKI 1997, KUŚ et al. 2002, KOSTRZEWSKA et al. 2004, 2006, ZARÓD 2009, JASKULSKI and JASKULSKA 2011).

The Warmian-Masurian voivodeship is characterized by significant landscape diversity owing to the wealth of its natural resources as well as its turbulent political and economic history. This article makes a reference to earlier studies of land use in different municipalities of the region (WANIC et al. 2002, KOSTRZEWSKA et al. 2004). The last analysis was performed 10 years ago, and this research attempts to analyze the changes that have taken place in the past decade, including Poland's accession to the European Union. The main objectives of the research were: to evaluate the changes in land use structure in the Warmian-Masurian voivodeship (Poland) in 2002–2012, and to compare land use evaluation methods used in the study.

Materials and Methods

This evaluation is based on habitat indicators developed by the Institute of Soil Science and Plant Cultivation (IUNG) (*Waloryzacja rolniczej przestrzeni*... 1981) as well and land use data covering the municipalities of the Warmian-Masurian voivodeship.

The abovementioned habitat indicators were developed on the basis of the assessment of the most important effects of habitat factors on the potential crops productivity. The analysis was performed for all municipalities in Poland. The point method was used by cited Authors in the assessment. The details of the method are included in Table 1.

Table 1
Evaluation of agricultural production area quality developed by the Institute of Soil Science and Plant Cultivation (IUNG) (*Waloryzacja rolniczej przestrzeni*... 1981)

Valuation index	Basis of evaluation	Range of points
Soil quality and agricultural suitability	Polish system of soil quality evaluation (classes and complexes of agrarian suitability of the soil)	18–95
Agroclimate	effect of climatic factors on crops yields increase	1–15
Land relief (lay of the land)	the share of particular types of relief (favourable and unfavourable for farming) within the agricultural land	0–5
Water relations	the share of particular categories of soil moisture (favourable and unfavourable for farming) within the agricultural land	0.5–5
Index of agricultural production area quality	total score of four indicators	19.5–120

The main body of data (for the analyzed municipalities, as at 1 January 2012) was provided by the Regional Center for Geodetic and Cartographic Documentation, courtesy of the Department of Rural and Agricultural Development of the Marshal's Office of the Warmian-Masurian voivodeship in Olsztyn. The remaining information was obtained from regional statistical publications (Basic information... 2003, Statistical Yearbook... 2003). In our analysis, rural and urban municipalities with the same name were classified as single units, and the area occupied by different types of land was summed up (a total of 101 municipalities were evaluated). The diversity in the land use structure in 2002 and 2012 was expressed with basic statistical data.

In the studied period, the dynamics of changes in land use in the analyzed municipalities was expressed by the redistribution coefficient (RC; after BAŃSKI 1997, modified), calculated based on five types of land (arable land, permanent grassland, orchards, forests, other):

$$RC = \sum_{j=1}^{m} r_j \cdot 200^{-1}$$

where:
m – number of land types,
j – 1, 2, ..., m,
$r_j = |W_j(t_1) - W_j(t_0)|$,
W_j – share of the j^{th} type of land in the municipality's area,
t_1 – final year (2012),
t_0 – starting year (2002).

The coefficient takes on values in the range of 0–1 (where values closer to 0 represent a more stable land use structure).

The strength of correlations (dependencies) between the elements of agriculturally productive area (quality and agricultural suitability of soils, agroclimate, land relief, water relations) and the predominant types of land was determined with the use of correlation coefficients.

The natural and agricultural diversity of the local landscape was evaluated with the involvement of three methods:

1. Land use trends in the studied municipalities were determined by the successive quotients method based on the ratio of agricultural land (R) to forests (F). Seven main land use trends were identified based on the six major quotients (KULIKOWSKI 1969). Land use categories were named in line with the nomenclature proposed by PAWŁOWSKI et al. (1992) and MAGIERA-BRAŚ (1992): R6 – predominantly agricultural; R5F1 – agricultural function with a share of forests; R4F2 – agricultural function with forests; R3F3 – mixed agricultural

and forestry production; R2F4 – forests with agricultural land; R1F5 – forests with a share of agricultural land; F6 – predominantly forests. Agricultural land use trends were identified based on the ratio of arable land to permanent grassland, and the following nomenclature was used: A6 – arable land, A5G1 – arable land with a share of grasslands, A4G2 – arable land with grasslands, A3G3 – mixed arable lands and grasslands, A2G4 – grasslands with arable land.

2. A random sampling method proposed by HERNIK (2001) was used to perform an ecological evaluation of land in the analyzed municipalities. In this method land use types (= ecosystems) are evaluated in view of their ecological attributes: water retention, degree of land erosion, sanitary and hygiene standards, health benefits and esthetic value. The details of the assessment are included in Table 2. For each municipality the average value of the index for evaluating agricultural and forest ecosystems was calculated according to the following formula:

$$\mathrm{AEEI} = \left[\sum_{j=1}^{m} \mathrm{EEI_j} \cdot A_j\right] \cdot \left[\sum_{j=1}^{m} A_j\right]^{-1}$$

where:
AEEI – average ecosystem evaluation index,
m – number of land types,
j – 1, 2, ..., m,
$\mathrm{EEI_j}$ – ecosystem evaluation index of the j^{th} type of land (meadows, pastures, orchards, arable land, forests),
A_j – area of the j^{th} type of land.

Table 2
Ecological evaluation of selected land use types using the random sampling method (HERNIK 2001)

Ecological attributes	Land use types				
	meadows	pastures	orchards	arable land	forests
Water retention	2	2	2	1	3
Degree of land erosion	2	2	2	1	3
Sanitary and hygiene standards	2	2	1	0	3
Health benefits	1	1	1	0	3
Esthetic value	2	1	1	1	3
Ecosystem evaluation index	1.8	1.6	1.4	0.6	3.0

0 – lack of positive impact on the environment, neutral impact; 3 – highly positive impact on the environment

3. Habitat indicators and elements of the land use structure (a total of 10 variables, evaluation of soil, agroclimate, land of relief and water relations, index of agricultural production area quality, share of farmland, arable land, perranent grassland, orchards and forests) were used to perform a *k*-means cluster analysis of the examined municipalities (FILIPIAK and WILKOS 1998). Six clusters of municipalities with similar characteristics were identified.

Results

Although the Warmian-Masurian voivodeship is generally recognized as an agricultural region, the local conditions are less than ideal for agricultural production (evaluation index of 66.2 points). On average, agricultural land has a 53.0% share of the local land use structure, and this parameter remained fairly stable in the past decade (Table 3). Similarly to the data recorded ten years ago, agricultural land accounts for more than 50% of total area in 70 municipalities. The number of municipalities where agricultural land has more than a 70% share in the local land use structure has decreased from 24 in 2002 to 19 in 2012. The median value of this parameter is higher than the weighted average for the region, but it is lower than that noted ten years ago. The past decade witnessed an insignificant drop in the share of arable land, grassland and orchards in the region, whereas an increase was noted in total forest cover. The above trend was observed in the vast majority of the analyzed municipalities. The median values illustrating the share of arable land, grassland and orchards decreased, and they were generally lower than the respective weighted averages for the region. The average share of forests increased, and

Table 3

Land use structure in the Warmian-Masurian voivodeship – statistical data

Category	Year	Municipalities			Region Average
		median	range of variation	coefficient of variation	
Agricultural land [%]	2002 2012	58.0 56.7	11.5–83.4 11.1–83.6	28.7 28.9	53.9 53.0
Arable land [%]	2002 2012	38.7 37.7	5.2–71.5 5.0–66.0	36.4 36.1	37.3 36.6
Permanent grassland [%]	2002 2012	16.7 16.2	5.4–32.1 5.3–38.0	34.5 35.5	16.4 16.3
Orchards [%]	2002 2012	0.12 0.09	0.01–1.11 0.00–0.74	97.6 102.0	0.16 0.11
Forests [%]	2002 2012	24.5 27.5	0.1–74.1 0.3–74.8	52.0 48.3	29.6 32.5

this trend was illustrated by a higher median value (which, however, remained below the average). In the group of 101 analyzed municipalities, relative agricultural area increased in only 17 administrative units, and the above changes were not accompanied by a simultaneous drop in forest cover. The arable acreage increased in 30 municipalities, and the said expansion was achieved by expanding agricultural area in five municipalities, whereas in 17 municipalities, it was accomplished by reducing the share of meadows, pastures and orchards. In 23 municipalities, arable land accounted for minimum 50% of the total area (down from 24 in 2002). The share of grasslands increased in only 28 municipalities, and in 17 administrative units, this increase took place at the expense of arable land or orchards. Relative orchard area increased in only one municipality (Dobre Miasto). This form of land use is still marked by the highest degree of spatial variation. The range of forest cover variation remained fairly wide and has not significantly changed, but the median value is higher than that noted ten years ago.

Spatial distribution of forest cover changes in 2002–2012 is presented in Figure 1. In the past decade, forest cover increased in all municipalities but two (Markusy, Iłowo-Osada), where an insignificant decrease was noted. In most municipalities, forest cover increase reached up to 5%. A rise of over 5% was observed in the municipalities of Pieniężno, Srokowo, Płoskinia, Lidzbark

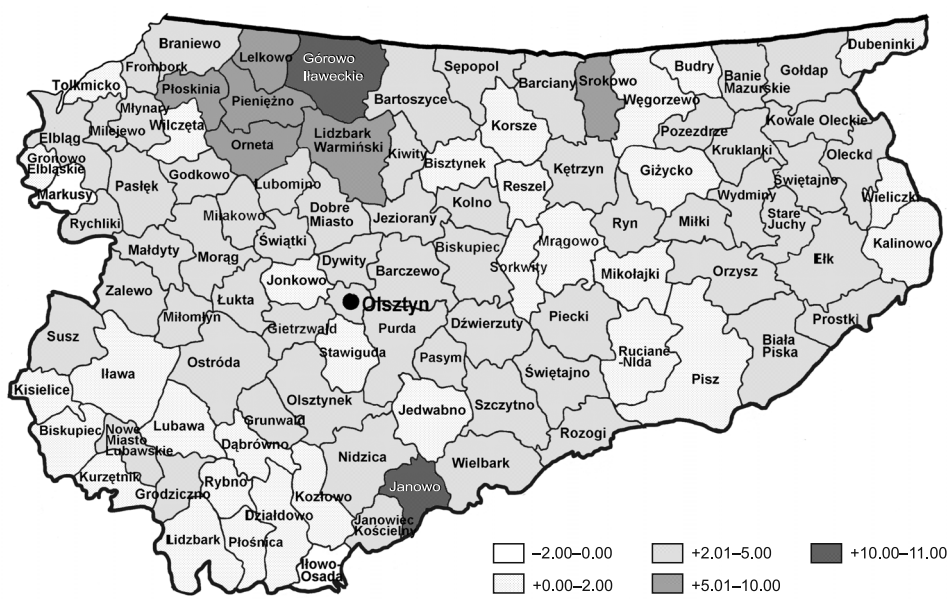

Fig. 1. Changes in share of forests in the municipalities of the Warmian-Masurian voivodeship in 2002–2012 [%]

Warmiński, Lelkowo and Orneta, and in the area of Górowo Iławeckie and Janowo it even exceeded the 10% level. With the exception of Janowo, these municipalities are located in the north-west part of Poland, where the share of forests in total lands amounts to between 20 and 40%. Currently, only in two municipalities (Gronowo Elbląskie and Markusy) forest cover is less than 10%. Although, in comparison to the situation in 2002, the number of municipalities with over 50% forest cover increased by only one unit, it is worth noting that the number of municipalities where the forest share is less than 20% decreased from 36 to 27. This decline indicates a positive change in municipalities with relatively low forest cover. Furthermore, in 31 municipalities, forests had a 33–34% share of the local land use structure, which exceeds the level planned by the National Afforestation Program (ŁONKIEWICZ 1995).

Low values of the redistribution coefficient point to a relatively stable land use structure in the past decade, although local variations were noted (Table 4). The most radical changes were observed in the municipality of Gronowo Elbląskie where around 20% of the area covered by arable land was transformed to grassland. Ruciane-Nida, the municipality with the highest forest cover (more than 70%), was characterized by the greatest structural stability.

The coefficients of correlation shown in Table 5 indicate that land-use planning decisions were made based on soil conditions, followed by the local hydrological regime.The share of forests in the municipalities' total area showed a strong negative correlation with the soil quality. The above mathematical relationship shows that the majority of forest land spreads over notably poorer grounds. Additionally, these areas are unsuitable for agriculture management due to inadequate water conditions, as evidenced by a negative correlation between forest cover and the relevant valuation index. Hunger for land, well-known in history, always pushed forest ecosystems to lands marked with the worst conditions. In the analyzed period, the strong positive correlation between soil quality and agricultural suitability, water relations and the share of agricultural and arable land, and the negative correlation between soil quality and agricultural suitability, water relations and forest cover were weakened. The above implies that contrary to the common practice of the 1980s and the 1990s (WANIC et al. 2002), afforestation programs no longer involve only soils of the poorest quality. The positive correlations between the share of grasslands and the quality of agriculturally productive area (all components, excluding agroclimate) and between the share of orchards vs. agroclimate and soil quality were strengthened.

Land use trends in the analyzed municipalities in 2012 are presented graphically in Figure 2. Agriculture was the predominant form of land use in 74 out of 101 municipalities (down from 77 municipalities in 2002). Five

Table 4
Dynamics of changes in the land use structure of the Warmian-Masurian voivodeship in 2002–2012 expressed by the redistribution coefficient (RC)

RC (intervals)	Municipalities
≤0.010	Ruciane-Nida (0.007), Lubawa (0.010)
0.011–0.020	Działdowo (0.015), Iłowo-Osada (0.016), Kurzętnik (0.016), Kalinowo (0.017), Iława (0.017), Lidzbark (0.017), Budry (0.018), Biskupiec (0.019), Dąbrówno (0.019), Dubeninki (0.019), Jonkowo (0.019), Sorkwity (0.019), Stawiguda (0.019), Olsztynek (0.020)
0.021–0.030	Janowiec Kościelny (0.021), Mrągowo (0.021), Tolkmicko (0.021), Rybno (0.022), Jedwabno (0.023), Kolno (0.,023), Reszel (0.023), Gołdap (0.024), Mikołajki (0.024), Nidzica (0.024), Ostróda (0.024), Piecki (0.024), Płośnica (0.024), Pozezdrze (0.024), Stare Juchy (0.024), Biskupiec (0.025), Kiwity (0.025), Pasym (0.025), Pisz (0.025), Barciany (0.026), Dźwierzuty (0.026), Nowe Miasto Lubawskie (0.026), Susz (0.026), Barczewo (0.027), Ełk (0,027), Gietrzwałd (0,027), Miłakowo (0,027), Purda (0,027), Miłki (0.028), Prostki (0.028), Grodziczno (0.029), Olecko (0.029), Małdyty (0.030), Miłomłyn (0.030), Pasłęk (0.030), Zalewo (0.030)
0.031–0.040	Biała Piska (0.031), Korsze (0.031), Kozłowo (0.031), Świętajno k. Szczytna (0.031), Wydminy (0.031), Szczytno (0.032), Dywity (0.033), Łukta (0.034), Ryn (0.034), Grunwald (0.035), Kruklanki (0.035), Świętajno (0.035), Frombork (0.036), Świątki (0.037), Wielbark (0.038), Kowale Oleckie (0.039), Młynary (0.039), Bisztynek (0.040)
0.041–0.050	Jeziorany (0.041), Wieliczki (0.043), Wilczęta (0.043), Olsztyn (0.044), Banie Mazurskie (0.045), Lubomino (0.046), Dobre Miasto (0.047), Morąg (0.047), Kętrzyn (0.048)
0.051–0.060	Godkowo (0.051), Lelkowo (0.051), Milejewo (0.052), Płoskinia (0.052), Giżycko (0.054), Rozogi (0.055), Węgorzewo (0.057), Lidzbark Warmiński (0.059), Elbląg (0.060), Kisielice (0.060), Orneta (0.060)
0.061–0.070	Braniewo (0.061), Bartoszyce (0.062), Srokowo (0.063), Pieniężno (0.066), Sępopol (0.066)
0.071–0.080	Rychliki (0.074)
0.081–0.090	Orzysz (0.087)
0.091–0.100	Markusy (0.094)
0.101–0.110	Górowo Iławeckie (0.106)
0.111–0.120	Janowo (0.112)
>0.121	Gronowo Elbląskie (0.220)
0.020	For the voivodeship

municipalities were classified as predominantly agricultural (R6), three of which (Elbląg, Gronowo Elbląskie and Markusy) are characterized by fertile soils of Żuławy Wiślane (Vistula delta) region. Ruciane-Nida was listed in the F6 category on account of its high forest cover and very few changes in the local land use structure. In comparison with 2002, changes in land use trends were noted in 14 municipalities: the significance of forest management increased in 12 municipalities, whereas only two municipalities (Elbląg, Lidzbark) placed greater emphasis on agricultural production (Table 6). In 89 municipalities,

Table 5
Coefficients of linear correlation between the percentage share of main land use categories and the valuation index of the analyzed area

Valuation index	Year	Percentage share in land use structure				
		agricultural land	arable land	grassland	orchards	forests
Soil quality and agricultural suitability	2002	0.569***	0.522***	0.287**	0.187**	–0.657***
	2012	0.559***	0.488***	0.359***	0.205**	–0.637***
Agroclimate	2002	0.083	0.166	-0.186	0.150	–0.104
	2012	0.069	0.142	-0.154	0.262**	–0.092
Land relief	2002	-0.013	-0.019	0.013	-0.054	0.114
	2012	0.002	-0.056	0.138	-0.034	0.105
Water relations	2002	0.403***	0.308**	0.357***	0.150	–0.464***
	2012	0.391***	0.272**	0.418***	0.152	–0.443***
Index of agricultural production area quality	2002	0.538***	0.499***	0.256**	0.212*	–0.624***
	2012	0.527***	0.462***	0.335**	0.228*	–0.606***

* – significant at $p = 0.05$; ** – significant at $p = 0.01$; *** – significant at $p = 0.001$

Table 6
Changes in the land use structure of the Warmian-Masurian voivodeship in 2002–2012

Municipality	Land use trend	
	2002	2012
Lidzbark	R3F3	R4F2
Elbląg	R5F1	R6
Młynary, Kowale Oleckie, Dobre Miasto, Rozogi	R4F2	R3F3
Braniewo, Lelkowo, Pieniężno, Prostki, Srokowo, Wilczęta	R5F1	R4F2
Lubawa, Świątki	R6	R5F1
Other municipalities	no change	

the predominant part of agriculturally productive area constitutes arable land (Figure 3). Grasslands with arable land (A2G4) were observed in only one municipality (Wielbark), whereas 11 municipalities were characterized by a mixed profile of arable lands and grasslands (A3G3). In 2002–2012, changes in agricultural land use (Table 7) were observed in 14 municipalities, and they involved an increase in arable area (eight municipalities) or the expansion of meadows and pastures (six municipalities). The most significant changes were observed in the municipality of Gronowo Elbląskie where the land use profile moved down two categories.

The ecological evaluation index for the region reached 1.72 (marking an increase in the past decade), and it was characterized by considerable spatial variation in the range of 1.08–2.77 across the studied municipalities (Figure 4). The lower limit of that range was significantly raised, and a minor increase was

Table 7
Changes in agricultural land management in the Warmian-Masurian voivodeship in 2002–2012

Municipality	Agricultural land use trend	
	2002	2012
Rozogi	A2G4	A3G3
Wilczęta	A3G3	A4G2
Dywity, Giżycko, Małdyty, Milejewo, Olecko, Zalewo	A4G2	A5G1
Banie Mazurskie, Markusy	A4G2	A3G3
Elbląg, Olsztyn	A5G1	A4G2
Gronowo Elbląskie	A6	A4G2
Kisielice	A6	A5G1
Other municipalities	no change	

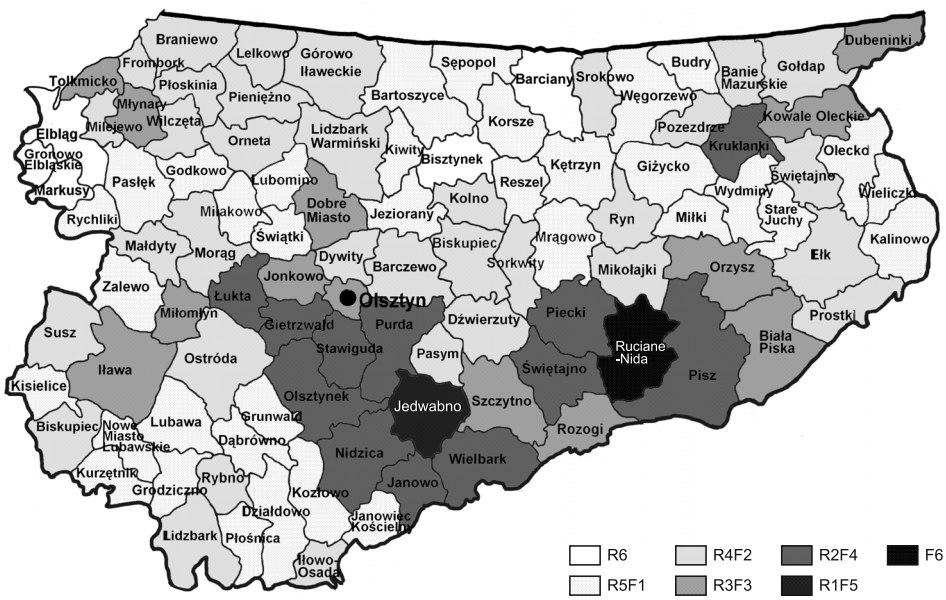

Fig. 2. Land use trends in the municipalities of the Warmian-Masurian voivodeship determined by the successive quotients method

also observed in the upper limit. Similarly to 2002, Ruciane-Nida and Jedwabno, municipalities with the highest forest cover, ranked highest with regard to ecological attributes (water retention, degree of land erosion, sanitary and hygiene standards, health benefits, esthetic value). The lowest value of the ecological evaluation index was noted in Lubawa. Gronowo Elbląskie

Fig. 3. Agricultural land management trends in the municipalities of the Warmian-Masurian voivodeship determined by the successive quotients method

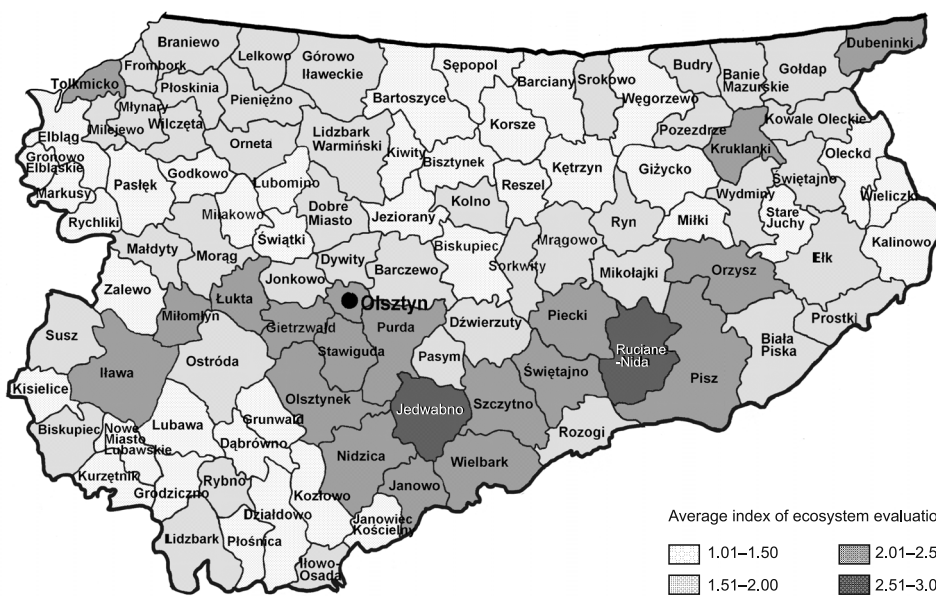

Fig. 4. Evaluation of agricultural and forest ecosystems in the municipalities of the Warmian--Masurian voivodeship

(which ranked last in 2002) moved up one category following the conversion of vast areas into grassland. The value of the ecological evaluation index exceeded 2.0 in 21 municipalities, most of which are situated in the central-southern part of the region.

In the past decade, the value of the ecological evaluation index decreased in only three municipalities, and it remained constant in six administrative units (Table 8). An increase was observed in the majority of the analyzed municipalities, and the most positive changes were reported in the Żuławy region (Elbląg and Gronowo Elbląskie).

Table 8

Changes in the value of the ecological evaluation index in the Warmian-Masurian voivodeship in 2002–2012

Change	Municipality
–	Giżycko, Iłowo-Osada, Milejewo
0	Bisztynek, Kozłowo, Płośnica, Rozogi, Tolkmicko, Wilczęta
+	Other municipalities
++	Braniewo, Frombork, Górowo Iławeckie, Lidzbark Warmiński, Markusy, Morąg, Olsztyn, Orneta, Pieniężno, Rychliki
+++	Elbląg, Gronowo Elbląskie
+	For the region (1.72)

– decrease in the range of 0.01–0.10; 0 – decrease or increase in the range of 0.00–0.01; + – increase in the range of 0.01–0.10; ++ – increase in the range of 0.10–0.20; +++ – increase in the range of 0.20–0.50

Similarly to the evaluation performed in 2002, the clustering analysis supported the identification of six groups (clusters) characterized by similar habitats and land use patterns (Table 9, Figure 5). Significant variations were not observed in the composition or the attributes of the studied clusters. Only four municipalities (Iłowo-Osada, Rybno, Węgorzewo, Zalewo) were moved to different groups. Clusters I and II cover a total of 31 municipalities characterized by the least supportive agricultural environment (low value of the index evaluating the agricultural production area and its constituent elements), most of which are situated in the southern and north-eastern parts of the region. Clusters I and II were identified in view of their land use structure, in particular the ratio of relative agricultural acreage to forest cover. Cluster I groups municipalities with a higher share of agricultural land (47.4%) and lower forest cover (38.6%), whereas cluster II characterizes administrative units with a relatively lower contribution of agricultural land (average of 28.5%) and extensive forest cover. In comparison with the analysis performed in 2002, cluster I decreased by two municipalities (Rybno and Iłowo-Osada), whereas cluster II remained unchanged.

Table 9

Values of variables in clusters of municipalities in the Warmian-Masurian voivodeship

Specification	Cluster (number of municipalities)					
	I (13)	II (18)	III (19)	IV (22)	V (15)	VI (14)
Soil evaluation	44.5	41.5	60.1	52.3	45.9	62.7
Agroclimate evaluation	7.3	8.0	8.7	8.1	7.8	8.5
Evaluation of land relief	3.2	3.6	3.5	3.1	3.3	3.8
Evaluation of water relations	2.9	3.0	4.0	3.4	2.9	4.1
Index of agricultural production area quality	57.9	56.2	76.2	66.9	59.9	79.0
Farmland [%]	47.4	28.5	61.4	53.9	68.9	74.8
Arable land [%]	30.5	17.4	43.0	35.7	55.2	53.2
Permanent grassland [%]	16.8	11.0	18.3	18.1	13.5	21.5
Orchards [%]	0.1	0.1	0.1	0.1	0.2	0.1
Forests [%]	38.6	53.5	24.5	29.0	20.4	14.3

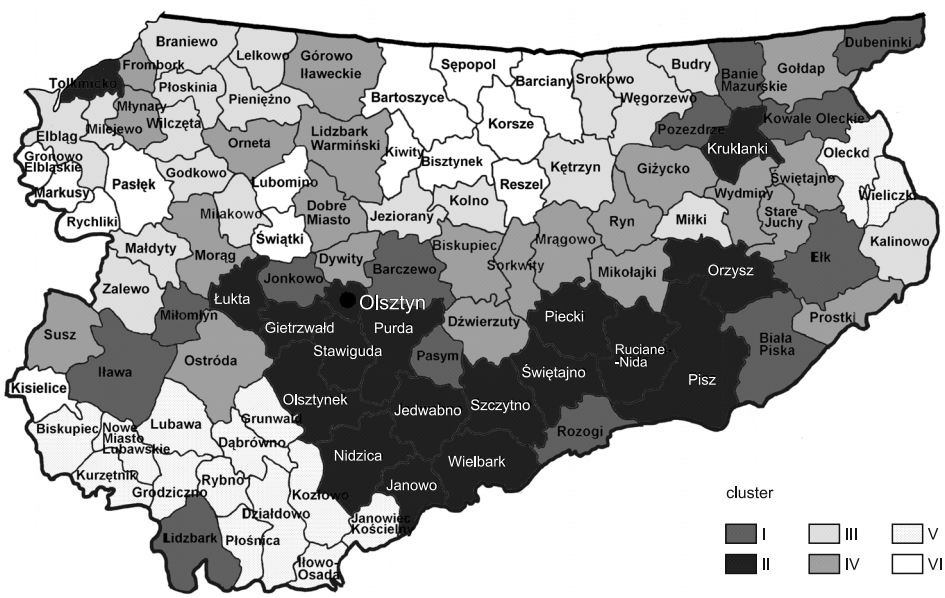

Fig. 5. Classification of municipalities in the Warmian-Masurian voivodeship into groups based on cluster analysis

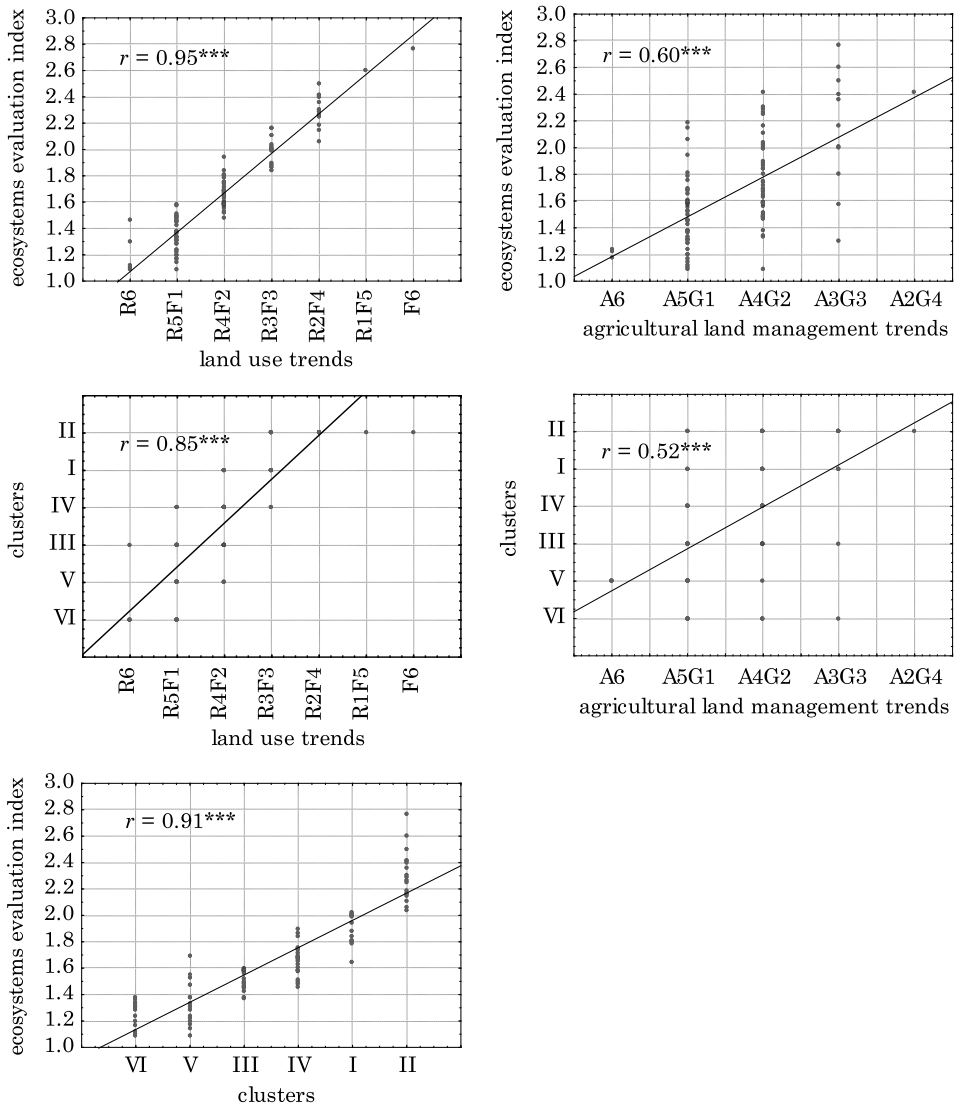

Fig. 6. Binary relationship between the methods used for classification of municipalities (r – coefficient of linear correlation; *** – r significant at $p = 0.001$)

Clusters III and VI are also characterized by similar habitats, and they bring together municipalities (19 and 14, respectively) with the most fertile soils, most supportive agroclimate and water relations. Clusters III and VI cover mostly administrative units in the central-northern and north-western parts of the region. Their distinctive feature is forest cover which is nearly

twice lower in cluster VI than in cluster III. Forest cover is negatively correlated with the area of land used for agricultural production. In cluster VI, agricultural land has the highest share of the local land use structure, and this group of municipalities is also characterized by the greatest contribution of grassland. In comparison with the previous evaluation (2002), cluster III was expanded by two municipalities (Węgorzewo and Zalewo), whereas no changes were reported in the structure of cluster VI.

Cluster IV comprises 22 municipalities, and it has lost two units on behalf of cluster III since the previous analysis. Cluster IV is largest in terms of both the number of municipalities and their combined area (24% of the region). Its municipalities are characterized by less than ideal farming conditions and land use patterns which are similar to the regional average.

Cluster V groups 15 municipalities (increase of two units at the expense of cluster I since 2002), situated mostly in the south-western part of the region (only two municipalities, Olecko and Wieliczki, are found in the eastern part). The municipalities are characterized by poor soils and relatively unfavorable farming conditions. Despite the above, agricultural production is the predominant type of land management, and cluster V is characterized by the highest average percentage of arable land in the local land use structure.

Despite procedural variations and differences in the pursued objectives, the analyzed methods for evaluating the land use structure delivered similar results (Figure 6). Municipalities were most effectively classified into the relevant categories by the highest averages method, followed by the ecological evaluation method and cluster analysis.

Discussion

Land use planning is a complex and long-term process (VERBURG et al. 2013, MEIYAPPAN et al. 2014). Land use and cover change have been identified as one of the prime determinants of global change with major impacts on ecosystems, global biogeochemistry and climate change (VERBURG et al. 2009). However, regardless of its global, regional or national significance, land management must begin at the local level (MEIYAPPAN et al. 2014). On the national and European scale,the Warmian-Masurian voivodeship stands out for its biodiversity and richness of the natural environment which include: varied topography, numerous lakes, and dense forest complexes (PZPWWM 2015). Half of the province are the areas covered by the legal protection of wildlife, including these of international rank (Natura 2000, CORRINE programme). The whole voivodship is located within the functional area of the Green Lungs of Poland. Warmia and Mazury region was included in the Baltic

Landscape project (SVENSSON 2014). For all the abovementioned reasons, rational land management of this area, preventing the loss of its natural values, seems to be worthy of not only regional, but also wider international interest.

In a classical study of land management practices in areas with undulating topography, NIEWIADOMSKI and KRZYMUSKI (1965) advocated the development of meadows in valleys with a slope of less than 2% and forests in areas with slope gradients higher than 35%, regardless of soil class. In the above publication, the proposed forest cover for lakelands was 24–27%. In 2002–2012, closer correlations were noted between the percentage share of grassland and land relief, and an increase in forest cover was observed in all municipalities of the Warmian-Masurian voivodeship. The threshold proposed by the above authors was exceeded in 58% of the analyzed municipalities. While the earlier afforestation land supply was mainly due to the crisis of agriculture in Poland (WANIC et al. 2002, KOSTRZEWSKA et al. 2004), currently the rise in forest cover also results from the implementation of the National Afforestation Program (ŁONKIEWICZ 1995) and the National Afforestation Policy (1997) which made afforestation a permanent element of Poland's spatial, ecological and economic policies. The aim of those policies is to increase Poland's forest cover to 30% in 2020 and 33% after 2050. Efforts will also be made to rearrange the boundaries between arable land and forests in order to bring greater cohesion to the local landscape, agricultural functions and forest management practices. According to the latest version (KALISZEWSKI et al. 2009) of the National Afforestation Program (ŁONKIEWICZ 1995), the goal of increasing Poland's forest cover to 30% is unlikely to be met by 2020 at the current rate of afforestation. The most realistic figure is 29.1–29.2%. The drop in the national afforestation rate after 2006 could be attributed to Poland's accession to the European Union and the greater popularity of agricultural subsidies over afforestation premiums. A reverse trend was observed in Warmia and Mazury where the area afforested in 2001–2008 exceeded the planned values (121%). According to the National Afforestation Program (ŁONKIEWICZ 1995), forest cover in the region should reach 31.4% in 2020, but the above level has already been exceeded (32.5%). The Warmian-Masurian voivodeship is particularly suited for afforestation programs. According to SIUTA and ŻUKOWSKI (2002), forest coverage in the region can be increased to 38% by planting forests on soils of the lowest quality class (VIz, VI and V). In a different study, SIUTA (2012) argued that the national forest cover can reach 45% with regional averages in the range of 30–60%. According to the cited author, Poland has a vast potential for increasing its forest coverage. Part of the fallow farmland has already been overgrown with trees and shrubs, but the above is not reflected by geodetic or statistical data.

According to URBAN (2009), the availability of direct agricultural subsidies after Poland's accession to the European Union has led to changes in land use structure, and it increased the share of meadows and pastures in total land area. The results of our evaluation did not confirm the above trend, and the relative area of arable land and grassland in the Warmian-Masurian voivodeship decreased in 2012. BAŃSKI (1997) observed that arable land has the highest share of the local land use structure in regions characterized by high quality soils. In Warmia and Mazury, the percentage of arable land was highly correlated with soil quality and the index of agricultural production area. It should, however, be noted that the above correlation was somewhat weakened in the past decade. According to BAŃSKI (1997), the percentage of grassland is higher in areas characterized by low quality of agricultural production area, namely regions with poor soils, unfavorable water relations and a shorter growing season. In the Warmian-Masurian voivodeship, the share of grassland was highly correlated with the quality of agricultural production area, and this relationship was further strengthened in the past decade.

Agriculture and forestry are the predominant types of land use in Europe. The key trends in European land use patterns include a decrease in agricultural areas, an increase in forest cover and the expansion of highly urbanized areas (EU-LUPA 2013). *t* the global scale, Europe is an anomalous continent in terms of forest trends. While the global forests shrink, the European forests expand (FRA 2010).Currently in Europe (without the Russian Federation), the average forest cover is estimated at 32,2%, and in the European Union (27, without Croatia) – at 37.6% (State of Europe's forests 2011). According to ZANCHI et al (2007), in Europe a general increase of forest area is reported, but trends differ between regions and can be due to different processes.

A few words should be said about the methodological aspects of the study. In this evaluation, we relied on several simple procedures that can be performed with a standard spreadsheet as well as on a more complex k-means cluster analysis. Changes in land use structure in vast and spatially differentiated areas are often illustrated with the use of maps, in particular color maps (WANIC et al. 2002). They can also be expressed by the redistribution coefficient. According to BAŃSKI (1997), even low values of the redistribution coefficient, which result from a short experimental period (as in this study), emphasize the variability of changes in land use structure and support an objective evaluation of their stable or variable character.

The choice of method for evaluating the diversity of the natural and agricultural environment should be determined by the aim of the classification process. According to BAŃSKI (1997), the successive quotients method fulfills two seemingly conflicting objectives: it provides detailed information about the

land use structure of a vast number of territorial units, while at the same time, the identified land use trends are sufficiently generalized to support graphic presentation and analysis. The cited author also observed that this objective method has been long used in agricultural geography, therefore, it enables a comparison of various research results. The random sampling method proposed by HERNIK (2001) was used to rank productive land (forests, meadows, pastures, orchards and arable land) in view of their ecological attributes: water retention, degree of land erosion, sanitary and hygiene standards, health benefits and esthetic value. The algorithm was developed based on published data and the author's observations. Forests were found to be the most "ecologically valuable" sites, whereas arable acreage scored the lowest number of points. The value of the average ecosystem evaluation index, a respective weighted average, was determined in the range of 0.6 to 3.0. The higher its value, the greater the ecosystem's impact on the local environment. Multidimensional analyses are increasingly used to classify agricultural sites (KUŚ et al. 2002, KOSTRZEWSKA et al. 2004, 2006, ZARÓD 2009, JASKULSKI and JASKULSKA 2011). The k-means cluster analysis identifies homogenous groups with similar characteristics, it reduces large groups of objects to several key categories for further analyses, and it supports comparisons of multi-attribute objects (ZARÓD 2009). In this method, homogenous regions can be identified without significant loss of information about individual municipalities.

Many authors point to the need for research on land management in terms of spatial and temporal variability (BAŃSKI 1997, CARRANZA et al. 2007, VERBURG et al. 2013, MEIYAPPAN et al. 2014). Landscape planning at the level of municipalities should follow the national planning policy, and, after Poland's accession to the European Union, requirements defined by relevant European directives and agreements (PZPWWM 2015). However, all rules implemented in landscape planning and management are expected to be based on the knowledge oflandscape ecology. The former faulty land management, mainly deforestation, is recognized as one of the causes of the steppization observed in central Poland, as well as in other countries of Central and Eastern Europe (PORĘBSKA and SADOWSKI 2007). The presented analysis of changes in land use in the municipalitiesgives the opportunity to predictthe trends for the years to come, including the possibility of changes in the function of agricultural land and forest.

The issue of land use and management is undertaken by specialists in many disciplines (BAŃSKI 1997), using more and more modern research methods (CARRANZA et al. 2007, MEIYAPPAN et al. 2014). In this context, the finding that despite procedural variations and differences in the pursued objectives the analyzed methods for evaluating the land use structure delivered similar results, is particularly significant.

Conclusions

The land use structure in the Warmian-Masurian voivodeship, largely determined by local natural conditions, was highly stable in the past decade (2002–2012). A minor decrease in the percentage share of arable land, grassland and orchards was noted, and it was accompanied by an increase in forest cover in all municipalities. The forest cover in Warmia and Mazury exceeds the level planned for 2020 by the National Afforestation Program (ŁONKIEWICZ 1995). Despite procedural variations and differences in the pursued objectives, the analyzed methods for evaluating the land use structure delivered similar results, and they point to clear regional variations in the natural and agricultural environment. The northern part of the region comprises mostly agricultural land, and it ranks lower with regard to its ecological importance. Agricultural acreage is also the predominant type of land use in the southwestern part of the region despite poor quality soils. The southern and south-eastern parts of the region are also characterized by low quality soils, they feature a higher share of forests and grasslands which increase their ecological significance and raise their recreational appeal.

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FOLIAR APPLICATION OF MICRONUTRIENTS (Cu, Zn and Mn) AND ITS EFFECT ON YIELD AND SELECTED MACRONUTRIENS CONTENT IN WINTER TRITICALE GRAIN

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K e y w o r d s: fertilization, yield components, nutritional value.

A b s t r a c t

The aim of the study was to determine the yield and its components and selected minerals (N, P, K, Ca, Mg, Na) in winter triticale grain as affected by foliar fertilisation with micronutrients, either used individually or in combination. A field experiment was carried out at the Educational and Experimental Station in Tomaszkowo (53°72 N; 20°42 E), Poland.

Regardless of the year, supplementation of NPK fertilisation with Cu resulted in an increase in the N and Na content in triticale grain. Application of Zn and Mn and the micronutrients in combination (Cu + Zn + Mn) resulted in an increase in phosphorus content. The year of the study affected the length of an ear at the plot fertilised with NPK fertiliser as well as the mass of 1.000 grains and Ca content in grain the NPK + Cu option. The weather conditions differentiated the grain yield and the content of N and Na in all the fertilisation options. Micronutrients applied individually and in combination affected the content of potassium in triticale grain. Foliar application of Cu + Zn + Mn stabilised the P content in grain in variable weather conditions. Pearson's correlation coefficient (r) showed a positive correlation between the content of N, Na and P in grain and the grain yield and mass of 1.000 grains. The content of K and N in grain was negatively correlated with the grain yield and the mass of 1.000 grains. A positive correlation was observed between the straw yield and the ear length and the potassium and sodium content in triticale grain.

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WPŁYW DOLISTNEGO OPRYSKIWANIA MIKROELEMENTAMI (Cu, Zn i Mn) NA PLONOWANIE I WYBRANE MAKROELEMENTY W ZIARNIE PSZENŻYTA OZIMEGO

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S ł o w a k l u c z o w e: nawożenie, komponenty plonu, wartość odżywcza.

A b s t r a k t

Celem pracy było określenie wysokości plonu i jego komponentów oraz wybranych składników mineralnych (N, P, K, Ca, Mg, Na) w ziarnie pszenżyta ozimego pod wpływem dolistnego dokarmiania mikroelementami stosowanymi pojedynczo lub łącznie. Doświadczenie polowe przeprowadzono w Zakładzie Dydaktyczno-Doświadczalnym w Tomaszkowie (53°72 N; 20°42 E), Polska. Niezależnie od lat badań, uzupełnienie podstawowego nawożenia NPK dolistnym dokarmianiem Cu spowodowało wzrost zawartości N i Na w ziarnie pszenżyta. Zastosowanie Zn i Mn oraz mikroelementów łącznie (Cu + Zn + Mn) spowodowało wzrost zawartości fosforu. Lata badań wpłynęły na zmianę długości kłosa w obiekcie nawożonym NPK oraz na MTZ i zawartość Ca w ziarnie w wariancie NPK + Cu. Warunki pogodowe różnicowały plon ziarna oraz zawartość N i Na we wszystkich obiektach nawozowych. Mikroelementy stosowane pojedynczo i łącznie wpłynęły na kształtowanie ilości potasu w ziarnie pszenżyta w latach badań. Zastosowanie dolistne Cu + Zn + Mn oddziaływało na stabilizację zawartości P w ziarnie w zmiennych warunkach pogodowych. Współczynnik korelacji *r* Pearsona wykazał dodatnią zależność pomiędzy zawartością N, Ca i P w ziarnie a plonem ziarna i masą tysiąca ziaren. Zawartość K i Na była ujemnie skorelowana z wielkością plonu ziarna oraz masą tysiąca ziaren. Dodatnio skorelowany były plon słomy i długość kłosa z zawartością K i Na w ziarnie pszenżyta.

Introduction

Obtaining high good quality yield in agricultural production depends largely on appropriate agrotechnical measures, including mineral fertilisation (DEKIĆ et al. 2014). Both macro- and micronutrients applied to soil and foliarly contribute greatly to adequate plant nutrition (ALARU et al. 2009, KNAPOWSKI et al. 2010, STANKOWSKI et al. 2015, WOJTKOWIAK et al. 2015). Copper, zinc and manganese are the most important micronutrients in the cultivation of cereal. They determine the effective use of macronutrients, especially nitrogen and phosphorus, in the production of biomass. As components and activators of enzymes, they participate in many metabolic reactions and play important physiological roles in plants. Copper regulates the transformations of nitrogen compounds and affects the chlorophyll formation process and the formation of cell walls. Manganese regulates the intensity of photosynthesis and partici-

pates in the transformation of nitrogen compounds and carbohydrates. Zinc plays a very important role in the synthesis of growth hormones, affecting the transformation of proteins and the synthesis of vitamins B, C, P and it also regulates phosphorus transformation in plants (HÄNSCH and MENDEL 2009).

Increasing attention has been attracted by beneficial effect of fertilisation of cereals with macronutrients in combination with micronutrients. The need for fertilisation with micronutrients arises from the decreasing use of mineral fertilisers and manure, which is a source of mineral nutrients (ADAMIAK et al. 2002). Foliar fertilisation with micronutrients is one of the most important methods of application of fertilisers in agricultural practice with the aim of increasing the concentration of mineral nutrients in grain (MALAKOUTI 2008, KNAPOWSKI et al. 2010, BOORBOORI et al. 2012, WOJTKOWIAK et al. 2015). According to RAWASHDEH and FLORIN (2015), the foliar application of nutrients facilitates their easy and quick absorption by penetrating the stomata or leaf cuticle and entering the cells. The spraying of micronutrients has led to the improving root growth of wheat and increased macro and micronutrient uptake (BAMERI et al. 2012).

The aim of the study was to determine the yield and its components and selected minerals (N, P, K, Ca, Mg, Na) in winter triticale grain as affected by foliar fertilisation with micronutrients, either used individually or in combination.

Materials and Methods

The field experiment was conducted at the Research and Education Centre of the University of Warmia and Mazury in Tomaszkowo (53°72 N; 20°42 E) in the years 2012–2013 on podzolic soil with the granulometric composition typical of medium silty clay (*Klasyfikacja uziarnienia gleb...* 2008). The granulometric composition, pH, content of $C_{org.}$, $N_{og.}$, P, K Cu, Zn, Mn and Fe were determined in soil samples taken before the experiment was set up, according to commonly applied methods. The experiment was set up by the method of random blocks in 3 replications. The major characteristics of the soil were presented in Table 1. The area of the plot for sowing was 6.25 m^2, and for harvesting – 4.0 m^2. Winter triticale of the Dinaro cultivar was sown after winter triticale at 194 kg ha^{-1} in 2011 and 203 kg ha^{-1} in 2012, density of 550 plants per m^2.

The following micronutrient fertilisation options were examined in the experiment:

– "NPK" (control) – Nitrogen was applied to all the plots at the dose of 90.0 kg ha^{-1}; the amount was divided in the following way: applied to soil – 54.0 kg ha^{-1} (urea 46%), during the tillering phase (BBCH 22–23) and foliarly

Table 1
Physical and chemical soil properties before the experiment started (average 2011–2012)

Measured parameters		Corresponding values
Granulometric composition		loam
pH in 1 mol/L KCl		4.95
Total organic C [g kg^{-1} DM]		7.9
Total N [g kg^{-1} DM]		1.01
Available nutrients [mg kg^{-1}]	P	64.1
	K	187
	Mg	75
	Cu	3.2
	Fe	1900
	Zn	7.5
	Mn	202

– 36.0 kg N ha^{-1} (10% solution of urea) during the shooting phase (BBCH 30–31), triple superphosphate (46%) at the dose equivalent to 30,2 kg P ha^{-1}, and potassium salt (56%) at the dose of 83,1 kg K ha^{-1}, as pre-plant application;
– "NPK + Cu" – Mineral fertilisation as in the "NPK" option + foliar application of 0.2 kg Cu ha^{-1} (1% solution of $CuSO_4$);
– "NPK + Zn" – Mineral fertilisation as in the "NPK" option + foliar application of 0.2 kg Zn ha^{-1} (1% solution of $ZnSO_4$);
– "NPK + Mn" – Mineral fertilisation as in the "NPK" option + foliar application of 0.2 kg Mn ha^{-1} (0,5% solution of $MnSO_4$);
– "NPK + Cu, Zn, Mn" – Mineral fertilisation as in the "NPK" option + foliar application of: 0.2 kg Cu ha^{-1}; 0.2 kg Zn ha^{-1}; 0.2 kg Mn ha^{-1}.

Cu, Zn and Mn (individually or in combination) were applied foliarly as aqueous solutions during the shooting phase (BBCH 30–31).

The temperature and amount of rainfall was monitored during the field experiment (Table 2). The average monthly air temperature during the triticale vegetation period were similar and they did not deviate from the multi-year average. The total rainfall in September 2011 was higher by 21.8 mm than 2012 year and by 10.6 mm than the multi-year average. The total rainfall in October and November 2011 was lower by 39.0 and 31.1 mm compared to 2012 and by 13.1 and 30.7 mm compared to the multi-year average. The total rainfall more than twice higher than the multi-year average recorded in April 2012. The total rainfall at the beginning of the tillering stage (May) during the years of study was similar. The total rainfall in June 2012 was much higher than the total rainfall in the subsequent year (2013). The rainfall in July 2012 and 2013 was similar, but it was 39% higher than the multi-year average.

Table 2

Weather conditions in 2011–2013 and the multi-year average of 1981–2010

Year	Month												
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX–VIII
Temperature [°C]													average
2011–2012	14.1	8.3	3.1	2.3	-1.7	-7.5	3.0	7.8	13.4	15.0	19.0	17.7	7.9
2012–2013	13.5	7.4	4.9	-3.5	-4.6	-1.1	-3.5	5.9	14.8	17.5	18.0	17.4	7.2
1981–2010	12.8	8.0	2.9	-0.9	-2.4	-1.7	1.8	7.7	13.5	16.1	18.7	17.9	7.9
Precipitation [mm]													sum
2011–2012	67.5	29.5	14.1	25.8	61.8	27.7	24.1	73.1	51.7	103.2	121.0	45.1	644.6
2012–2013	45.7	68.5	45.2	11.8	44.1	22.6	18.1	28.5	54.5	61.2	121.9	37.6	559.7
1981–2010	56.9	42.6	44.8	38.2	36.4	24.2	32.9	33.3	58.5	80.4	74.2	59.4	581.8

Agrotechnical practices included skimming done as soon as the forecrop had been harvested. Post-harvest remnants were covered by pre-sow ploughing and harrowing before winter triticale was sown. A cultivation and sowing unit was used immediately before sowing in order to mix the mineral fertilisers and to prepare the soil for sowing. Weeds were destroyed using herbicides in 2012 (BBCH 21–29) – Mustang Forte 195 SE (a.i. florasulam 5 g, aminopyralid 10 g, 2.4 D 180 g) in dose of 1.0 dm^{-3} ha^{-1} and Puma Universal 069 WG (a.i. fenoxaprop-P-ethyl 69.0 g) in dose of 1.2 dm^{-3} ha^{-1}. In 2013 – were used (BBCH 21–29) Atlantis 12 OD (a.i. iodosulfuron methyl sodium 2 g; mesosulfuron methyl 10 g) in dose of 0.45 dm^{-3} ha^{-1} + Sekator 125 OD (a.i.: iodosulfuron methyl sodium 25 g, amidosulfuron 100 g) in dose of 0.15 dm^{-3} ha^{-1}. Protection against pests and diseases was not performed.

The grain was harvested during the maturation phase (BBCH 89–92) with a plot harvester. Samples of grain from individual years were analysed in the laboratory; the following were determined: N by the Kjeldahl method, Ca, Mg, K and Na by atomic absorption spectrometry (flame technique) and phosphorus by the vanadium-molybdenum method in material mineralised earlier with H_2SO_4 with H_2O_2 as an oxidiser.

The results were processed with STATISTICA 10.0 software (StatSoft, Tulsa, Oklahoma, USA). The statistical calculations were performed with two-way ANOVA. Apart from the basic parameters, standard deviation and statistically homogeneous groups were determined using Tukey's test at $\alpha = 0.05$. Coefficients of linear correlation (Pearson's r) were calculated.

Results and Discussion

The yield of winter triticale ranged from 5.53 t ha^{-1} to 8.73 t ha^{-1} and the yield of straw – from 6.00 t ha^{-1} to 7.50 t ha^{-1}. This is more (by 3.50 and 3.34 t ha^{-1}, respectively) than the average yield obtained in agricultural practice in Poland and worldwide (FAO 2014) – Table 3. Fertilisation with NPK with Zn application contributed to an increase (not statistically) by 1.8% of the yield compared to the NPK fertilisers. Other fertilization treatments of micronutrients did not differ significantly from the control of NPK fertilization.

Table 3

Grain, straw yield and yield components of winter triticale

Year	Fertilisation treatments				
	NPK	NPK + Cu	NPK + Zn	NPK + Mn	NPK + Cu + Zn + Mn
Grain yield [t ha^{-1}]					
2012	$5.82^{b} \pm 0.08$	$5.63^{b} \pm 0.26$	$5.93^{b} \pm 0.45$	$6.02^{b} \pm 0.49$	$5.53^{b} \pm 0.33$
2013	$8.52^{a} \pm 0.46$	$8.73^{a} \pm 0.29$	$8.67^{a} \pm 0.61$	$8.45^{a} \pm 0.63$	$8.18^{a} \pm 0.33$
Ave.	$7.17A^{B} \pm 1.51$	$7.18A^{B} \pm 1.72$	$7.30^{A} \pm 1.57$	$7.23^{A} \pm 1.42$	$6.86^{AB} \pm 1.48$
Straw yield [t ha^{-1}]					
2012	$7.00^{a} \pm 0.50$	$6.92^{a} \pm 0.38$	$7.17^{a} \pm 1.38$	$7.50^{a} \pm 0.25$	$6.92^{a} \pm 0.80$
2013	$6.00^{a} \pm 0.66$	$6.50^{a} \pm 0.25$	$6.58^{a} \pm 0.52$	$6.25^{a} \pm 0.50$	$6.42^{a} \pm 0.14$
Ave.	$6.50^{A} \pm 0.76$	$6.71^{A} \pm 0.37$	$6.87^{A} \pm 0.98$	$6.88^{A} \pm 0.77$	$6.67^{A} \pm 0.58$
Ear length [mm]					
2012	$99.0^{a} \pm 6.73$	$90.9^{ab} \pm 2.38$	$91.4^{ab} \pm 3.45$	$87.8^{ab} \pm 4.69$	$93.5^{ab} \pm 1.99$
2013	$81.8^{b} \pm 1.08$	$87.4^{ab} \pm 5.61$	$82.5^{b} \pm 1.58$	$86.3^{ab} \pm 8.62$	$81.9^{b} \pm 3.25$
Ave.	$90.4^{A} \pm 10.4$	$89.2^{A} \pm 4.30$	$87.0^{AB} \pm 5.43$	$87.1^{AB} \pm 6.26$	$87.7^{AB} \pm 6.83$
Number of grains per ear					
2012	$45.4^{a} \pm 5.97$	$43.9^{a} \pm 3.32$	$41.1^{a} \pm 2.11$	$41.6^{a} \pm 1.51$	$41.0^{a} \pm 1.53$
2013	$39.2^{a} \pm 0.42$	$43.5^{a} \pm 4.60$	$39.1^{a} \pm 2.22$	$41.5^{a} \pm 5.70$	$38.9^{a} \pm 4.24$
Ave.	$42.3^{AB} \pm 5.11$	$43.7^{A} \pm 3.60$	$40.1^{B} \pm 2.21$	$41.6^{B} \pm 3.73$	$39.9^{B} \pm 3.07$
Mass of grains per ear [g]					
2012	$1.38^{a} \pm 0.14$	$1.29^{ab} \pm 0.24$	$1.17^{a} \pm 0.08$	$1.25^{a} \pm 0.01$	$1.23^{a} \pm 0.12$
2013	$1.21^{a} \pm 0.09$	$1.38^{a} \pm 0.12$	$1.21^{a} \pm 0.09$	$1.26^{a} \pm 0.31$	$1.15^{a} \pm 0.06$
Ave.	$1.30^{A} \pm 0.14$	$1.33^{A} \pm 0.18$	$1.19^{A} \pm 0.08$	$1.25^{A} \pm 0.20$	$1.19^{A} \pm 0.09$
Mass of 1.000 grains [g]					
2012	$31.5^{bc} \pm 1.56$	$31.0^{c} \pm 0.91$	$31.2^{bc} \pm 0.80$	$32.3^{abc} \pm 1.05$	$31.1^{bc} \pm 0.95$
2013	$33.3^{abc} \pm 0.92$	$34.3^{a} \pm 0.39$	$33.5^{abc} \pm 0.20$	$32.7^{abc} \pm 0.09$	$33.6^{ab} \pm 0.92$
Ave.	$32.4^{A} \pm 1.53$	$32.7^{A} \pm 1.90$	$32.3^{A} \pm 1.34$	$32.5^{A} \pm 0.71^{A}$	$32.4^{A} \pm 1.61$

Ave.: average, ± standard deviation

a,b ... *A,B* ... Averages in rows followed by the same letter are insignificant ($\alpha < 0.05$)

According to WOJTKOWIAK et al. (2015), foliar application of $CO(NH_2)_2$in combination with a multi-component fertiliser (Ecolist), which contains both macro-nutrients and a set of micro-nutrients, contributed to an increase in the yield of spring triticale cultivated in the same conditions. They attribute great importance to the micronutrients present in multi-component fertilisers, which take part in fixing nitrogen, thereby contributing to achieving the maximum grain yield.

According to the results of the statistical analysis, the year of study has a significant effect on the yield in all the fertilisation options under study, where the yield increased by 40.4% (NPK + Mn) to 55.1% (NPK + Cu) in 2013. Such differences may have been caused by the total rainfall and its distribution, as confirmed by studies of KALBARCZYK (2010), BRZOZOWSKA and BRZOZOWSKI (2011), ESTRADA-CAMPUZANO et al. (2012) and BRZOZOWSKA et al. (2016). Excessive rainfall, especially during the period of intensive growth and development of triticale in 2012 (73 mm in April, including 32 mm in the second 10-day period of April, 42.6 mm in the second 10-day period of May and 103 mm in June, including 50.9 mm in the third 10-day period) resulted in an increase in the vegetative mass (straw yield) and a decrease in the grain yield.

The application of NPK fertilisers enriched with micro-nutrients applied foliarly in this study did not have a significant effect on the structural features of the triticale yield. According to BAMERI et al. (2012), the negative response to foliar application of (Zn + Fe + Mn) on wheat growth may be attributed to micronutrient uptake problems and antagonistic effect among Fe, Zn and Mn in their combination. The years of study affected some elements of the yield structure. The longest ear was achieved in the first year of study (2012), when mineral fertilisation (NPK) alone was applied. The mass of 1.000 grains increased by 10.6% following application of NPK + Cu in 2013 (compared to 2012). According to JASKULSKI and PIASECKA (2007), the yield of winter triticale depends much more on variable habitat conditions than on the forecrop. According to SPYCHAJ-FABISIAK et al. (2005) and ALARU et al. (2009), a high yield of triticale grain and protein content can be achieved as a result of nitrogen application at 90–120 kg ha^{-1}.

JANUŠAUSKAIT (2014) claims that variable weather conditions affect the effectiveness of nitrogen fertilisation, thereby diversifying the number of ears (from 72.6% to 83.5%), kernels per ear (from 46.6% to 94%.) and mass of 1.000 grains (from 84.5% to 92.7%). The findings of a study conducted by ZEIDAN et al. (2010) indicate that spraying plants with Fe, Mn and Zn results in increased yield of grain, straw, TKW, number of kernels per ear and protein content in grain. Foliar application of micronutrients (Fe=1%, Mn=2%, Zn=2%, Cu=1%, B=1%) at different growth stages of wheat increased plant height, grains per spike, mass of 1.000 grains, biological yield, harvest index, straw and grain yield (KHAN et al. 2010).

Table 4

Content of macronutrients in the grain of winter triticale [g kg^{-1} DM]

Year	Fertilisation treatments				
	NPK	NPK + Cu	NPK + Zn	NPK + Mn	NPK + Cu + Zn + Mn
N					
2012	$18.09^{c} \pm 0.17$	$17.16^{d} \pm 0.02$	$17.97^{c} \pm 0.27$	$17.97^{c} \pm 0.36$	$17.86^{c} \pm 0.10$
2013	$20.06^{a} \pm 0.36$	$19.65^{ab} \pm 0.17$	$19.36^{b} \pm 0.20$	$19.88^{ab} \pm 0.10$	$19.83^{ab} \pm 0.17$
Ave.	$19.07^{A} \pm 1.11$	$18.41^{C} \pm 1.38$	$18.67^{BC} \pm 0.79$	$18.93^{AB} \pm 1.07$	$18.84^{AB} \pm 1.08$
P					
2012	$1.70^{d} \pm 0.06$	$1.62^{d} \pm 0.040$	$1.61^{d} \pm 0.02$	$2.30^{c} \pm 0.04$	$2.40^{c} \pm 0.06$
2013	$2.70^{b} \pm 0.05$	$2.70^{b} \pm 0.030$	$3.30^{a} \pm 0.10$	$2.70^{b} \pm 0.05$	$2.30^{c} \pm 0.03$
Ave.	$2.20^{C} \pm 0.54$	$2.16^{C} \pm 0.59$	$2.45^{A} \pm 0.93$	$2.50^{A} \pm 0.22$	$2.35^{B} \pm 0.07$
K					
2012	$4.25^{a} \pm 0.06$	$1.46^{f} \pm 0.03$	$1.29^{g} \pm 0.05$	$1.32^{g} \pm 0.03$	$1.27^{g} \pm 0.09$
2013	$4.16^{ab} \pm 0.09$	$4.08^{bc} \pm 0.06$	$4.00^{c} \pm 0.03$	$3.21^{e} \pm 0.03$	$3.84^{d} \pm 0.039$
Ave.	$4.21^{A} \pm 0.08$	$2.77^{B} \pm 0.14$	$2.64^{C} \pm 0.15$	$2.27^{E} \pm 0.10$	$2.55^{D} \pm 0.14$
Mg					
2012	$0.90^{a} \pm 0.01$	$0.90^{a} \pm 0.20$	$0.97^{a} \pm 0.16$	$1.10^{a} \pm 0.10$	$0.67^{a} \pm 0.49$
2013	$1.07^{a} \pm 0.21$	$0.93^{a} \pm 0.06$	$1.03^{a} \pm 0.46$	$1.10^{a} \pm 0.20$	$1.17^{a} \pm 0.15$
Ave.	$1.00^{a} \pm 0.17$	$0.92^{a} \pm 0.13$	$1.00^{a} \pm 0.03$	$1.10^{a} \pm 0.14$	$0.92^{a} \pm 0.04$
Ca					
2012	$2.26^{b} \pm 0.14$	$2.14^{b} \pm 0.21$	$2.28^{b} \pm 0.11$	$2.29^{b} \pm 0.20$	$2.38^{b} \pm 0.32$
2013	$2.66^{ab} \pm 0.26$	$3.16^{a} \pm 0.27$	$2.47b \pm 0.19$	$2.47^{b} \pm 0.15$	$2.42^{b} \pm 0.19$
Ave.	$2.46^{a} \pm 0.29$	$2.65^{a} \pm 0.60$	$2.38^{a} \pm 0.17$	$2.38^{a} \pm 0.19$	$2.40^{a} \pm 0.24$
Na					
2012	$0.768^{b} \pm 0.007$	$0.984^{a} \pm 0.001$	$0.656^{c} \pm 0.015$	$0.625^{c} \pm 0.015$	$0.522^{d} \pm 0.002$
2013	$0.404^{e} \pm 0.002$	$0.238^{f} \pm 0.000$*	$0.178^{g} \pm 0.001$	$0.194^{g} \pm 0.001$	$0.194^{g} \pm 0.002$
Ave.	$0.586^{B} \pm 0.006$	$0.611^{A} \pm 0.002$	$0.417^{C} \pm 0.092$	$0.409^{C} \pm 0.092$	$0.358^{D} \pm 0.026$

Ave.: average, ± standard deviation
a,b ... A,B ... Averages in rows followed by the same letter are insignificant ($\alpha < 0.05$)
0.000* – value bellow 0.000

According to MAKARSKA et al. (2010), the level of minerals depends on the genotypes of parent forms. STANKOWSKI et al. (2015) pointed to the high stability of macro-nutrient content in grain of triticale caused by nitrogen fertilisation. According to NOGALSKA et al. (2012), single- and multi-component fertilisers affected the mineral composition of grain and straw of spring triticale in a similar manner. Mineral fertilisers, applied in combination with micronutrients or micronutrient fertilisers, increase the yield, but they also increase the mineral content in triticale grain (MALAKOUTI 2008, KHAN et al.

2010, KNAPOWSKI et al. 2010). According to WOJTKOWIAK et al. (2014) habitat conditions in the years of study diversified the macro-nutrient content.

This study revealed a diverse effect of mineral fertilisation (NPK) without, and in combination with, micronutrients on the content of selected macronutrients in grains of winter triticale of the Dinaro cultivar (Table 4). BAMERI et al. (2012) reported that root growth in wheat was improved by spraying micronutrients, which led to an increase in the uptake of macro and micronutrients. BOORBOORI et al. (2012) found that the content of proteins and components of barley yield increased following foliar spraying with micronutrients. Supplementation of fertilisation with micronutrients applied individually or in combination reduced the content of nitrogen in grain. This may have been caused by a low level of potassium in grain of the cultivar in question, which can be a sign of nitrogen metabolism disorders (MAATHUIS 2009). In effect, this results in reduction of the amount of protein produced by the plant regardless of micronutrient fertilisation. A significant increase in the content of N was caused by supplementation with Cu and Zn (by 3.5% and 2.1%, respectively). A higher content of N in kernels harvested in 2013 was determined at all the plots. A statistical analysis confirmed that the nitrogen content in grain increased from 7.7% (after additional spraying with zinc) to 10.6% (at a plot fertilised with Mn) in the second year of the study. In a study conducted by WARECHOWSKA (2004a, 2004b) and WARECHOWSKA et al. (2004), foliar application of Mn, Zn and Cu significantly increased the content of protein proper in grain of spring triticale of the Maja cultivar compared with plants which were fertilised with nitrogen alone. In presented study additional foliar application of micronutrients (Zn, Mn and Cu + Zn + Mn) resulted in an increase in the content of phosphorus (by 11.4%, 13.6% and 6.8%, respectively). The phosphorus content was found to be higher in all the plots in 2013 (by 43.2% on average). The content of potassium in triticale grain ranged from 1.27 to 4.25 g kg^{-1}. Additional spraying with micronutrients considerably reduced potassium content in triticale grain. No external signs of a deficit of the element were observed during the vegetation period. Supplementation of the basic NPK fertilisation with micronutrients resulted in a multi-fold increase in potassium content in grain in the second year of the study (2013) compared to the first year (2012). A considerable decrease in potassium content may be attributed to several processes associated with an antagonistic relationships, both in soil and in the plant itself. This especially applies to the interaction of K with Ca, Mg, Na ions (MAATHUIS 2009), as well as micronutrients, such as Zn and Cu (MALVI 2011). Additional fertilisation with micronutrients did not change significantly the content of Ca and Mg in triticale grain. The content of Ca increased by 47.7% in 2013 following supplementation with Cu. A study conducted by WOJTKOWIAK and DOMSKA (2009) also showed that additional

application of copper, zinc and manganese fertilisers did not cause any significant difference in the accumulation of phosphorus and calcium and, in most cases, potassium in grain of triticale of the Gabo cultivar. The additional application of Cu resulted in an increase in Na content in triticale grain by 4.3%. Supplementation of fertilisation with micronutrients (Zn, Mn and Cu + Zn + Mn) in the other plots reduced the content of Na. Grain obtained in the first year of the study (2012) contained much higher levels of sodium. MOOSAVI and RONAGHI (2011) reported that the high applications of essential nutrients like Fe and Mn decreased absorption of other nutrients by roots or transportation from roots to plant shoot.

The results of a statistical analysis expressed by Pearson's correlation coefficient (r) showed a positive correlation between the content of N, Na and P in grain and grain yield and mass of 1.000 grains (Table 5). Particularly noteworthy is the strong correlation between the content of N and P and the grain yield (r = 0.895 and r = 0.804, respectively) and mass of 1.000 grains (r = 0.735, r = 0.661, respectively). It was found in a study conducted by BRZOZOWSKA et al. (2016) that there was a significant negative correlation between the content of phosphorus and nitrogen in grain and grain yield of winter triticale, which confirms the findings of BOY and FOSSATI (1995). The high yield of grain obtained in their study was connected with low concentrations of minerals, such as N, P, K, Mg, Fe, Mn, Zn and Cu, and a high concentration of Ca. This shows that production oriented towards obtaining high yield may lead to a decrease in the nutritional value of triticale grain. Unlike in the case of N, Ca and P, the content of K and N in grain in this study was negatively correlated with the grain yield (r = -0.606, r = -0.866, respectively) and the thousand kernel weight (r = -0.373, r = -0.728, respectively). A positive correlation was observed between the straw yield and the ear length and the potassium content (r = 0.513, r = 0.405, respectively) and sodium content (r = 0.461, r = 0.432) in triticale grain.

Table 5
Correlations between content of macronutrients and grain, straw yield and yield components (average 2012–2013)

Specifications	N	P	K	Mg	Ca	Na
Grain yield	0.895	0.804	–0.606	n.s.	0.520	–0.866
Straw yield	–0.546	–0.395	0.513	–0.369	–0.433	0.461
Ear length	–0.371	–0.454	0.405	n.s	–0.367	0.432
Number of grains per ear	n.s.	n.s.	n.s	n.s.	n.s	n.s.
Mass of grains per ear	n.s.	n.s.	n.s	n.s.	n.s	n.s.
Mass of 1.000 grains	0.735	0.661	–0.373	n.s.	0.513	–0.728

Conclusion

1. NPK fertilization with the addition of Zn significantly increased the grain yield of winter triticale. The other micronutrients did not affect the increase in grain yield.

2. Regardless of the year of study, supplementation of NPK fertilisation with Cu resulted in an increase in the N and Na content in triticale grain. Application of Zn and Mn and the micronutrients in combination (Cu + Zn + Mn) resulted in an increase in phosphorus content. Micronutrients applied individually and in combination affected the content of potassium in triticale grain. Foliar application of Cu + Zn + Mn stabilised the phosphorus content in grain in variable weather conditions.

3. The year of the study affected the length of an ear at the plot fertilised with NPK fertiliser as well as the mass of 1.000 grains and Ca content in grain the NPK + Cu option. The weather conditions differentiated the grain yield and the content of N and Na in all the fertilisation options.

4. Pearson's correlation coefficient (r) showed a positive correlation between the content of N, Na and P in grain and the grain yield and mass of 1,000 grains The content of K and N in grain was negatively correlated with the grain yield and the thousand kernel weight. A positive correlation was observed between the straw yield and the ear length and the potassium and sodium content in triticale grain.

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WELFARE OF FARMED DEER – PRACTICAL ASPECTS

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K e y w o r d s: *Cervus elaphus*, *Dama dama,* equipping, handling, feeding, stress.

A b s t r a c t

In the 20th century, members of the family *Cervidae*, in particular the red deer (*Cervus elaphus*), the fallow deer (*Dama dama*) and the sika deer (*Cervus nippon*), became relatively popular farm animals. Deer farming continues to develop, albeit at different rates, in Europe and worldwide. In deer farms, the fulfillment of the Five Freedoms listed in the Codes of Recommendations for the Welfare of Livestock (FAWC 2014) may involve somewhat different measures in comparison with other livestock animals due to the specific biological requirements, behavioral patterns and low levels of domestication in cervids.

Numerous requirements have to be fulfilled to achieve high levels of welfare in animal farms, including deer farms. They include an adequate diet that meets the animals' nutritional needs, the use of appropriate materials and solutions for building farm equipment and devices, selection of adequate personnel and appropriate animal handling procedures. In deer farms, several fundamental conditions have to be met to guarantee minimum welfare levels. Additional requirements that improve the welfare of farmed red deer and fallow deer have been formulated based on many years of observation, experience and scientific research.

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DOBROSTAN FERMOWYCH JELENIOWATYCH – ASPEKTY PRAKTYCZNE

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Słowa kluczowe: *Cervus elaphus*, *Dama dama,* wyposażenie, obsługa, żywienie, stres.

Abstrakt

W XX wieku niektóre gatunki z rodziny jeleniowatych, zwłaszcza jeleń europejski (*Cervus elaphus*), daniel (*Dama dama*) i jeleń sika (*Cervus nippon*), stały się dość popularnymi zwierzętami gospodarskimi. Hodowla jeleniowatych rozwija się, choć w różnym tempie, w Europie i na świecie. W ich utrzymaniu fermowym powinno być spełnionych pięć zaleceń dotyczących wolności, wymienionych w Kodeksie dobrostanu zwierząt gospodarskich (FAWC 2014). Ze względu na specyficzne wymagania biologiczne, brak wzorców zachowań i niski poziom udomowienia jeleniowatych może wiązać się to z zastosowaniem odmiennych wskaźników, w porównaniu z innymi zwierzętami gospodarskimi.

Wiele wymagań musi być spełnionych, aby osiągnąć wysoki poziom dobrostanu zwierząt gospodarskich, w tym jeleni. Należą do nich odpowiednia dieta, która zaspokaja potrzeby żywieniowe zwierzęcia, stosowanie odpowiednich materiałów i rozwiązań do budowy sprzętu i urządzeń, wybór odpowiedniego personelu i odpowiednich procedur obsługi zwierząt. W hodowli jeleniowatych musi być spełnionych kilka podstawowych warunków, aby zagwarantować minimalny poziom dobrostanu. W pracy przedstawiono wymagania sformułowane na podstawie wieloletnich obserwacji, doświadczeń i badań naukowych, które po zastosowaniu poprawiają dobrostan hodowanych jeleni i danieli.

Introduction

Man has been using animals to satisfy own needs for millennia. Human attitudes towards animals evolved throughout history, from early primitive hunting, through domestication to industrial livestock production. A positive change in man's attitude towards animals was observed in the late 20th century (PHILIPS 2009). This period witnessed the birth of the Animal Welferism movement which relies on the basic premise that humans have the right to use animals as long as the animals' biological needs, including access to food, water, protection, shelter, medical care, freedom from pain and suffering, are met (PHILIPS 2009, GODDART 1998, ETIM et al. 2013). In 1965, those needs were outlined as the Five Freedoms in the Codes of Recommendations for the Welfare of Livestock developed by the Farm Animals Welfare Council (FAWC 2014):

1. Freedom from hunger and thirst – ready access to water and diet to maintain health and vigor.

2. Freedom from discomfort – provision of comfortable resting space, shelter and an appropriate environment.

3. Freedom from pain, injury and disease – prevention or rapid diagnosis and treatment.

4. Freedom from fear and stress – provision of conditions and treatment which eliminate mental suffering.

5. Freedom to express normal behavior – provision of sufficient space, proper facilities and appropriate company of the animal's own kind.

The above welfare requirements constitute the basic principles for animal handling, and they should not be debatable in a civilized society. The objective of research and husbandry measures should be to develop breeding methods which ensure that profits are increased by fully catering to the animals' biological needs rather than through ruthless exploitation (PIASENTIER et al. 2005).

In deer farms, the fulfillment of the Five Freedoms listed in the Codes of Recommendations for the Welfare of Livestock (FAWC 2014) could involve somewhat different measures in comparison with other livestock animals due to the specific biological requirements, behavioral patterns and low levels of domestication in cervids.

This paper discusses the key welfare requirements for deer farms, including the optimal environment for females and their offspring during the breeding season.

Welfare of farmed deer – discussion

Designing, building and equipping deer farms

Deer farms can be established on various types of land, including areas where other types of agricultural production are not profitable, provided that grasslands are available. The quality of pastures can be improved and maintained through various farming operations, including fertilization, mowing left-over vegetation and reseeding pastures with valuable species of grasses and legumes. The size of the land for building a deer farm is determined by various factors, including the farmed species or breed, topography of the site, availability and quality of pastures, cost and availability of supplementary feed, distance from markets/processors, and enterprise structure (TUCKWELL 2003).

A farm should be an integral site to guarantee full functionality for animals and the staff. Pens, shelters and all farm facilities should be connected to a handling facility joined by a raceway for herding deer. Different layouts can be used, depending on the shape, surface and size of the land plot, production intensity and enterprise structure. A rectangular layout with a centrally positioned raceway is the most popular solution. The raceway runs adjacent to all pens, joining them with one another and with the handling facility. In this layout, animals can be moved in all directions. This solution can be modified by connecting selected pens with the largest paddock via a narrowing raceway or a small raceway with a handling shed. The layout of a deer farm should ensure problem-free movement of animals between paddocks and from/to the raceway and the handling facility. According to HAIGH et al. (2005), injuries sustained during herding, catching and transport of animals are the most common causes of death in white-tailed deer (*Odocoileus virginianus*) farms. For this reason, the farm and the handling facility should be designed with utmost care. Deer are more likely to pace up than down the fence, they change direction at an angle of less than 90° from the fence and bypass obstacles from a distance. This knowledge should be used to plan gates and mark strategic locations with planks and poles. Gates should be positioned in corners for practical reasons. A centrally located gate is a "hole in the wall", and deer may be unwilling to cross it. Corner gates allow for the use of long and uninterrupted stretches of fencing mesh that can be fixed and joined without complications. This solution also facilitates the movement of animals between opposing pens. According to TUCKWELL (2003), „V" gates as well as three-way and four-way gates best serve the purpose. All three solutions deliver numerous possibilities and are highly practical. Gates should be at least 3.5 m wide to create access for machinery. Raceways, entrances and suboptimally located gates should be shuttered to make them more visible for animals and to prevent deer from jumping over them. Raceway walls should be tightly shuttered to prevent injury, and they should be higher than netting (more than 2 m). Fallow deer can clear fences 2 m tall, therefore, fences in fallow deer farms should be even higher (DEFRA 1989). Raceways should not turn at right angles, which can lead to crowding and the risk of stampede with disastrous consequences (MATIELLO 2009). Raceway width should be adjusted to the animals' specific needs.

Mesh fencing is a crucial part of a deer farm, and next to stock purchase, it constitutes one of the highest initial expenses. The proper deer netting has fixed knots, it is highly resistant and acts as a shock absorber, therefore, animals that hit against the fence are not seriously injured and do not damage the fence. Young animals are particularly prone to hitting the fence, and the resulting mortality is much higher in farms that do not use flexible netting. Shock-absorbing netting keeps deer safe from predators (dogs and foxes can

kill up to 50% of calves/fawns) because mesh openings are smaller at the bottom. Netting should be bedded in the ground to prevent predators from digging under the fence and entering the farm. A typical fence should have the height of 1.8 to 2 m. High voltage electrified wire on outriggers may be used on the outside of the fence to protect deer from feral dogs. GODDARD et al (2001) studied behavioral responses of red deer to fences of five different designs. They reported the best results (animals did not pace the fence) for a conventional fence (netting with the height of 1.9 m) and a fence with an inverted "L" shape (with the height of 90 cm and horizontal mesh with the width of 80 cm at the top). Deer frequently paced the remaining types of fences: a low fence (90 cm) with offset electric wire, a low (90 cm) double fence (two rows of mesh separated by a distance of 1 m), and a tall fence (1.9 m) with four webbing tapes above.

Every deer farm should provide the animals with appropriate shelter to guarantee high welfare standards (MAF 2007, DEFRA 1989, DEFRA 2013, MATIELLO 2009). The hair coat does not protect deer perfectly against adverse weather and every farm should offer quarters that shelter the animals from wind, rain and snow. Shelter and shade can be provided in a variety of ways by relying on natural features (valleys, indentations), groups of large trees and shrubs, hedges or man-made objects such as buildings, haystacks and straw bales (MAF 2007). Farms situated in open areas could benefit from planting trees. Young trees should be encased with shutters, metal grids or mesh to protect them from browsing, and larger trees should be adequately secured to prevent stags/bucks from chewing the bark and rubbing their antlers on tree stems. Farmers in New Zealand (MAF 2007) and the United Kingdom (DEFRA 2013) are also advised to provide the animals with resting spaces on dry ground, in particular if the farm is situated in a damp or waterlogged area, by spreading large amounts of straw on raised ground. Shelter (visual isolation) also minimizes aggressive behavior in animals. Artificial shelters and visual barriers built with the use of fabric and plastic sheeting in pens for red deer hinds reduced aggressive behavior by 60% in comparison with hinds kept in an open paddock (WHITTINGTON and CHAMOVE 1995). Pregnant females should be provided with shelter in the perinatal period and for minimum two weeks postpartum even in the absence of extreme weather events (MAF 2007, DEFRA 1989, MATIELLO 2009).

The topography of the farm site is a very important consideration. Trees, shrubs, roads, ponds, hills and valleys are the key elements of the local landscape. Trees provide shelter and shade, and indentations and valleys can serve a similar purpose. Hilly terrain promotes physical exercise and contributes to animal welfare. According to the recommendations of the New Zealand Deer Code of Welfare, females should be kept in hilly paddocks before mating

because regular exercise improves their physical condition (elimination of excessive fat), contributes to reproductive success (fertilization efficiency) and lowers the risk of complications during parturition (MAF 2007). A deer farm does not have to incorporate a forest which is not an attractive pasture area and is costly to fence in. A forest offers shelter from the wind, in particular in winter, and provides visual isolation, but in order to serve this purpose, it is enough if a forest is situated in the vicinity of a deer farm. Laneways should be wide enough to enable farming machines to supply feed, water, hay and straw to all facilities or to mow grass. If possible, calving/fawning paddocks should be situated far from roads. Cervids have a preference for natural bodies of water over artificial water reservoirs. A farm should not be set up on large swamps because deer eagerly hide in such areas, and they are difficult to chase out, which increases the risk of the animals going wild. Ponds and marshes are potential sources of parasites and their indirect hosts (snails). For this reason, an absence of natural ponds in pens could be a certain advantage because artificial reservoirs (concrete rings, plastic containers, troughs) contain clean water and can be used to administer vitamins, micronutrients and medication. Despite the above, ponds and water-logged territories enable deer to express their natural behavior and wallow in mud. The animals roll around in mud to get rid of external parasites, cool off during hot weather and to mark the ground with their scent in the mating season (CLUTTON-BROCK et al. 1982, MATIELLO 2009). Water facilities should be designed to minimize fouling and wastage. Demand for water increases during spells of hot weather. Stags/bucks need more water during the rut, hinds/does – during lactation, and calves/fawns – in the first 10 days after weaning (MAF 2007). According to Animal Welfare Guidelines for deer farms in Tasmania, fallow deer does need around 10 liters of water per day (DEPI 2008).

Handling facilities

Every deer farm requires a handling yard where animals can be safely divided into groups, prepared for transport and subjected to various health and maintenance procedures, including deworming, tagging, antler cutting and pregnancy diagnosis. Handling facilities should be designed and built with utmost care in view of the needs of the farmed species and herd size. Special attention should be paid to the entrance to a handling facility, the type of materials used and the construction method. A conventional handling yard is designed on a rectangular plot, and it features several smaller pens for separating the animals, a utility shed and a loading ramp. The handling pen can also be circular with a utility shed and crush in the center and holding pens

along the perimeter. The design and construction of deer handling facilities are described in detail in *Safe Practical Deer Yards, a New Zealand guidebook* by CUDBY (2004). Handling facilities should be designed to minimize the risk of injury (absence of protruding elements, no spaces between shutter planks, solid and smooth walls, non-slippery flooring or no flooring) and stress (gates that do not produce noise, problem-free movement of animals, darkened sheds) and increase operating efficiency (at least some facilities should be roofed, the utility shed should have electric power and running water, handling facilities should be sufficiently lit to examine the animals and diagnose any signs of disease or injury). Cervids, in particular fallow deer, settle much more easily in darkened premises or in complete dark, and they are more eager to move from darker to lighter facilities. The above observations should be taken into account when designing handling yards to facilitate handling operations and minimize stress resulting from movement and immobilization (MAF 2007, MATIELLO 2009). Deer should be handled quietly with care and patience. The operators should speak in a soft voice to calm the animals down, get them accustomed to human scent and send the message about the operator's presence in a dimly lit shed. All operations should be performed quietly, quickly, efficiently and according to the same routine. Cervids are herd animals, and individuals should not be isolated from the group. If an individual has to be quarantined or separated from the group for health reasons, it should have visual contact with other animals. Cervids should not be handled in periods of adverse weather, including thunder and hailstorms, strong winds or excessive heat (MAF 2007).

Every handling facility should be equipped with a crush to immobilize deer, perform grooming operations, administer medical treatment and slaughter animals. The choice of an appropriate crush should be dictated by the farmed species, the size of the herd and how tame the animals are. Crushes are generally divided into two categories: mechanical and hydraulic. Mechanical crushes include box-type pens and crushes where the animal is restrained between two walls. In the latter type, an animal enters the crush, and it is suspended by its shoulders between two skewed walls, with its feet off the floor. The animal is released when one of the sides is moved away from the other. Those types of crushes are suitable for red deer and fallow deer, but due to their small size and lack of a head restraining mechanism, they are not highly effective for immobilizing stags/bucks, in particular those with hard antlers. This restraint method is relatively stressful for animals, but provides safe and direct access to the animal and is relatively inexpensive. Box-type pens are made of two parts which, when closed, immobilize the animal and leave access to head. They are suitable for fallow deer, and they facilitate blood sampling, tagging, medical tests and slaughter. Hydraulic crushes offer the

greatest comfort and enable the operator to access the animal from all sides. Animals are restrained between hydraulically controlled, padded walls. Hydraulic crushes have one or two moving sides. Upon entering the crush, the animal is immobilized together with the head. A hydraulic crush is easily adjusted to the animal's size, which minimizes the risk of injury, increases safety and facilitates various operations, including antler cutting. The greatest disadvantage of a hydraulic crush is its high price. Blood, hair and bird droppings should be regularly removed from a crush. Handling facilities should also be kept clean and free of animal feces (MAF 2007).

Deer should be familiarized with handling facilities and management routines from an early age to reduce apprehension and assist handling (MAF 2007).

Nutrition

Quality pastures are the key to healthy nutrition in a deer farm. For best results, animals should graze in a rotation system where the height of grass cover reaches 10–12 cm, and when it is reduced to 5–6 cm, they are moved to a different pasture. In this approach, animals eat young leaves with the highest nutritional value. Under suboptimal conditions (drought, poor soils and low quality sward), a pasture should be stocked with 5–10 red deer hinds or 10–20 fallow deer does with offspring per hectare. If forage growth is insufficient, animals should be provided with supplementary feed. The nutritional requirements of cervids change on a seasonal basis. Physiological processes and behaviors, such as molting, antler growth, appetite, reproduction, lactation are strongly correlated with day length. The most energy consuming processes, including lactation and antler growth, take place in periods characterized by the highest availability of food sources. Winter feeding should rely on high-quality feed with high energy content to satisfy the maintenance requirements of animals, prevent weight loss and minimize mortality. The energy demands of deer increase by 20–30% if the animals are not adequately sheltered from wind and snow. Nutrition levels and feed utilization are also influenced by the animals' age, sex, size, body condition, health status, level of activity and exercise, weather conditions and provision of shelter (MAF 2007). Young animals, stags/bucks that are growing antlers, hinds/does in the last trimester of pregnancy and lactating females have higher energy requirements which should be met by administering high quality feed. All animals should have free access to feed to minimize aggressive interactions and to cover the nutrient requirements of subordinate individuals (MATIELLO 2009). In winter or in large commercial farms where pastures are not the main source of nutrition,

animals should be provided with high quality hay, barley straw or silage to increase dietary fiber intake. Poisonous plants, plastic waste, strings, wire and other man-made objects that can be ingested by deer should be removed from pastures. Changes in diet should be introduced gradually to enable ruminal flora to adjust to new food and to prevent digestive problems (MAF 2007, DEPI 2001). Good nutrition is an important tool for animal stress management. When an animal is improperly fed, stress has even greater negative impact on his health. The period of stress for deer is the time when the content of proteins in the fodder is low. Deer demand on the crude protein (CP) is minimally 6–7% to proper functioning rumen. However, the diet containing less than 10% CP results in inferior antler growth and muscle development. Optimal protein amount for the proper development of bones and muscles in the daily feeding of deer is 12–16%. In addition to this component in the diet of deer you cannot be missed the calcium and phosphorus (PERKINS 1991). Detailed information about the nutrient requirements of farmed deer, feed types, daily rations and energy demand subject to the animal's sex, age and physiological state can be found in the literature (ASHER et al. 1996, ASHER et al. 2005, LANDETE-CASTILLEJOS et al. 2002).

Handling stress and its influence on animal welfare

Cervids which have not developed positive contact with humans, excluding individuals that were raised by humans, are difficult to race, catch and handle. The stress of restraint can also significantly compromise welfare (RUSHEN et al 1999).

In a study of red deer calves, MATIELLO (2009) demonstrated that regular contact with humans during management routines decreases the percentage of heart rate peaks associated with human presence in the pen. Grigor et al. (1998) examined the responses of one-year-old red deer hinds to five procedures: transport, immobilization in a crush, human presence, visual isolation from the herd, and escape. Stress responses were measured by the speed with which animals entered the raceway leading to a handling facility. Hinds were most stressed after 5 minutes of immobilization in a crush and after 5 minutes of transport. Animals that were not subjected to additional stressors were the first to enter the raceway. POLLARD and LITTLEJOHN (1996) evaluated the influence of pen size on the behavior of red deer stags in various seasons. In large paddocks, aggression levels and behavioral signs of stress (fence pacing, vertical head movements) were lower regardless of season than in small pens, but the observed trends were more highly expressed in summer. If several individuals have to be temporarily separated from the herd, males should be

provided with adequate space, in particular in summer months preceding the rut, to maintain acceptable welfare standards. CARRAGHER et al. (1997) used automatic blood sampling kits and heart rate monitors to demonstrate that isolation, human contact and restraint cause stress responses. Immobilization in a crush was the greatest stressor. It has been shown that by taking blood from the animal deprived physically of the possibility of movement hematological and biochemical parameters indicated less stress, unlike in the animals which were treated with sedative pharmacological or shot gun. It was observed slightly ($P>0.05$) elevated parameter values such as: AST (aspartate aminotransferase), ALT (alanine aminotransferase), GGT (gamma-glutamyl), GLDH (glutamate dehydrogenase), the amount of albumin and WBC (total leukocyte count) in blood from animals immobilized physically, and a lower amount of Hb (hemoglobin), RBC (red blood cell count) and PVC (total volume of blood elements). Higher WBC in blood of deer that were deprived physically of the possibility of movement as compared to chemical methods, may be the result of shrinkage of the spleen and isolated by a catecholamine, other parameters may be caused myopathy. The amount of glucose in the blood was increased regardless of the manner of collecting the blood, and may be caused by stress, which activates the sympathetic nervous system and thus increases the secretion of adrenaline. However, high glucose levels in the animals chemically deprived of movement may be due to the use xylazine that in ruminants causes hyperglycemia and, consequently, weaken the immune mechanism (VENGUST at al. 2006). There were no significant differences between chemical appeasing and shooting the animal. It seems, therefore, that the fleeting stress caused by physical anchorage is less intrusive than administration of pharmacological agents. The hypothalamic-pituitary-adrenal axis was activated during each stress response, but the measured parameters quickly returned to norm when the animal was reunited with the herd. The above results could suggest that handling procedures do not significantly compromise deer welfare, but it should be remembered that stress and fear that accompany management routines can lead to injury or even death.

RECARTE et al. (1998) investigated the ways in which fallow deer, kept in a park, responded to human presence. The distance to which the animals moved away from humans was determined by the sense of security offered by the environment (paddock design) and the degree to which deer were familiarized with humans. Does with offspring were much more likely to run away from humans that other groups of fallow deer, which could be attributed to the female instinct of protecting the young from potential aggressors. POLLARD and LITTLEJOHN (1995) and CHAYA et al. (2006) observed that red deer have highly individual responses to human contact and handling procedures. According to CHAYA et al. (2006), temperament plays an important role during

selective breeding. They reported that calves obtained by crossbreeding red deer and wapiti were calmer during catching and administration of medicine. Timidity and fear of humans are traits that are partially inherited from parents, but they can be alleviated by breeders through adequate handling and by culling the most problematic individuals.

According to MANTEUFFEL et al. (2009), rewarding farm animals for displaying certain types of behavior can improve animal welfare, minimize fear of humans and facilitate handling. Such behaviors include responding to specific cues (visual or auditory), regular and frequent calling of individuals to a feeding facility, calling cow groups to milking parlors or presenting horses with visual patterns on a screen which indicate access to oats. The above authors postulated that cognitive enrichment based on instrumental behaviors and positive responses to specific situations can minimize stress levels associated with changes in housing environment or handling. Auditory cues are used to stimulate feeding behaviors in a large open space moose farm in Kostroma, Russia (MINAEV et al. 1984). A similar approach could be used in deer farms.

Segregation and stocking density

European fallow deer and red deer are highly social animals that inhabit large areas in sexually segregated groups during anestrus season and in mixed-sex groups during the rut. Even under intensive management conditions, deer tend to maintain sexual segregation, in particular during the birth season. Mixed-sex groups are the most common type of social aggregation when space is limited, in particular during feeding activity (MATIELLO et al. 1997). Breeders should allow deer to engage in natural behaviors and when needed maintain sexually segregated groups by providing animals with appropriately designed pens, managing and stocking the herd in accordance with high welfare standards. A herd should be divided into groups. It is determined by the size of the farm and the handling facility. Males and females should be segregated for the most part of the year, and they can be additionally divided into age groups (1- and 2-year olds and older). Spike bucks rub off the velvet on their antlers more quickly than older bucks, and segregation can prevent aggressive young bucks from attacking mature males. The segregation of hinds/does into age groups can improve the overall condition of the youngest females and fertilization rates. Calves/fawns which are weaned in winter should be segregated into sex groups in spring. This approach promotes early cutting of single spikes and separation of selected calves/fawns for sale or slaughter. Segregation also supports feed optimization to accommodate the

specific needs of a given group. Individuals of the same age group consume similar amounts of feed, which would not be the case if they were kept together with older and more dominant animals. Segregation also reduces losses associated with overfeeding dominant group members. Members of sex- and age-segregated groups, including pregnant hinds/does, weaned calves/fawns and stags/bucks, can be fed different diets that are adapted to their specific nutritional needs.

Pasture stocking rates determine individual weight gains, natural behaviors and stress levels, and they influence animal welfare. BLANC and THÉRIEZ (1998) analyzed the effect of stocking density on social behaviors, daily activity levels and weight gains in one-year-old red deer hinds kept in a pasture. The herd was divided into two experimental groups: a low density group (LD, 37 animals/ha) and a high density group (HD, 150 animals/ha). Aggressive behaviors such as kicking, biting, head hitting and threatening poses were much more frequently noted in group HD. Total grazing time did not differ significantly between groups and group HD females grazed more often but for shorter periods of time than LD group females. Simultaneous grazing was also lower in group HD. LD group hinds grew at a faster rate. Stocking density was more likely to influence the growth rates and grazing behavior of subordinate individuals than dominant animals. The cited authors concluded that high stocking density causes stress during social contact, which influences grazing activity and growth rates, in particular in subordinate individuals. The frequency of antagonistic behaviors displayed by red deer calves increased with stocking density (MATIELLO 2009). POLLARD and LITTLEJOHN (1996) also observed that aggression levels in red deer stags increased with a reduction in pen size and individual space.

In their natural habitats, red deer and fallow deer females leave the herd in the perinatal period and return 1–2 weeks later (CHAPMAN and CHAPMAN 1975, CLUTTON-BROCK et al. 1982). In the farm environment, small pen size, high stocking density, synchronized calving/fawning and shortage of shelters can prevent deer from expressing their natural behaviors, thus disrupting the natural cycle. As a result, many hinds/does give birth at the same time in constrained space, which can discourage females from bonding with their offspring. In farms, hinds/does assist other females in bringing up their offspring or raise foreign offspring. Human presence is a source of additional complications, and animals are stressed even when the observer remains in hiding (WASS et al. 2004). Research indicates that hinds which are unable to bond with their young often abandon their offspring, which is never observed in wild deer populations (ASHER et al. 1996). In crowded calving paddocks, newborns hidden in grass are accidentally trodden on by other animals, calves are "stolen" by females that have never calved or have miscarried, the

offspring of hinds that are unable to find an isolated place for delivery may be stillborn, and hinds pace and clear the fence in an attempt to find appropriate shelter. In deer farms, rapid fence pacing could be a sign that a female will shortly go into labor (POLLARD et al. 1998, WASS et al. 2003, ASHER et al. 2007, ASHER et al. 2014). Fence pacing intensifies when humans are present in the vicinity of the calving paddock (POLLARD et al. 1998) and in smaller and overcrowded paddocks (ASHER et al. 2007). Fence pacing is a stress response, and breeders should provide pregnant females with sufficient space to minimize unwanted behaviors. Stress during delivery can lead to complications, stillbirths and abandonment of offspring. Hinds that go into delivery near the fence will be disturbed by other animals which can accidentally tread on the newborn. Calves can also attempt to cross the fence, often with lethal consequences. Pregnant hinds should also have access to isolated shelters where they can hide from other members of the group. In their natural habitat, hinds give birth in areas overgrown with shrubs, reeds, nettles and ferns where newborns spend the first few days of their lives (POLLARD and STEVENS 2003). Calving/fawning paddocks should be provided with an adequate number of sheltered sites where the young will spend the first few weeks of their lives. In deer farms, the design and construction of breeding areas where calves/fawns are born and reared should be well planned to ensure the success of breeding operations and high levels of animal welfare.

Designing and building calving/fawning paddocks

Deer should be provided with a sufficient number of sheltered sites during delivery and offspring rearing. Natural shelters, such as shrubs, nettles, ferns and tall grass, are preferred, but if not available on the site, they should be replaced with man-made facilities. Calving/fawning paddocks are crucial in every farm. A shortage of secluded facilities where hinds can give birth away from other members of the group raises stress levels, increases the risk of complications and calf mortality (WASS et al. 2003). If suitable calving/fawning areas are overcrowded, females can choose to give birth in suboptimal locations, such as under the fence or in an open area, thus exposing the newborns to excessive solar radiation (MATIELLO 2009). HODGETTS et al (2002) reported that the availability of secluded areas contributes to animal welfare. They also observed that the type (natural or man-made) and shape of shelters are important. Natural shelters (nettles, ferns) were more frequently used than artificial structures. Calving/fawning paddocks should be situated far from busy roads and noisy sites (MATIELLO et al. 1997, POLLARD and STEVENS 2003).

In densely stocked paddocks with an insufficient number of hiding places, calves/fawns can be licked, sniffed, pushed or kicked by other females. Disturbed calves/fawns may begin to pace the fence, where they can be trodden on by other individuals. Young deer can sustain injuries in contact with aggressive females, and some calves/fawns attempt to cross the fence in search for a better hiding place, often with lethal consequences. For this reason, calving/fawning paddocks should be spacious, stocking rates should be kept low and adequate to the number of available shelters (WASS et al. 2004). The New Zealand Deer Production Guide (BEATSON et al. 2000) proposes a test for evaluating calving/fawning paddocks. Shelters receive points for fulfilling specific criteria that contribute to animal welfare in the perinatal period and during offspring rearing. The following factors are evaluated: size of the calving/fawning paddock, distance from roads and other disturbing sites, topography of the site (percentage of flat and undulating areas), presence of hills, trees, tree trunks, rocks, ponds, rivers, protective green belts around the paddock, percentage of shaded area, type of fence netting, type of pasture, plant species and plant height, stocking density in the paddock.

AUDIGÉ et al. (2000) analyzed factors that influence the survival of fallow deer fawns between birth and weaning. The experiment was performed on hinds which were diagnosed as pregnant 50–70 days after the rut. The offspring of 17% of primiparous hinds and 9.2% multiparous hinds did not survive until weaning. Most deaths occurred in the perinatal period or several weeks after birth. The cited authors concluded that reproductive success is determined by individual traits as well as by herd management during birth and in later periods. The body condition scores (BCS) of hinds significantly influenced the survival of offspring and were positively correlated with the body weights of hinds in winter. The administration of high quality feed to females already in early stages of pregnancy can considerably contribute to reproductive success. The discussed study revealed that stocking density influences the survival rates of offspring. According to the cited authors, high stocking density does not pose a threat in itself, but it can have highly negative consequences when combined with other factors, such as malnutrition or shortage of safe areas where hinds can give birth or hide their offspring. In the above study, tagging at birth did not influence the survival rates of calves. Weather was an important consideration, and moderate temperatures without extreme weather events were most conducive to healthy growth and development. Drought and high temperatures contributed to the risk of dehydration and hyperthermia, whereas overcast weather and rainfall could lead to hypothermia. Immediately after a thunderstorm, dead calves were found in paddocks with a limited number of sheltered sites. The presence of mature stags in the calving paddock also had a negative impact on offspring survival. The number of calves that survived until weaning increased when caretakers

regularly visited breeding areas to examine the health condition of mothers. Breeders who take good care of their herds are familiar with the animals' needs and respond quickly to any problems. According to the cited authors, the following requirements should be met to maximize breeding success: hinds should be in good health before the rut, females should not lose weight in winter, the number of early conceiving hinds should be increased, adult hinds and stags should be managed separately during calving and rearing.

The New Zealand Animal (Deer) Code of Welfare (MAF 2007) recommends the following best practices for handling pregnant and lactating hinds/does:

1. Hinds/does should be provided with appropriate feed during pregnancy and lactation to ensure that their BCS is in the range of 3–4 (on a 0–5 scale).
2. Stress, especially through overcrowding, should be minimized during calving/fawning to reduce losses in newborn calves/fawns. The provision of feed, water and shelter should be planned appropriately to minimize disturbance.
3. During calving/fawning, mothers and their offspring should not be disturbed or exposed to unfamiliar events that disrupt their routines.
4. Hinds/does with calving/fawning difficulties should be given assistance.
5. Stocking density in calving/fawning paddocks should be reduced already before calving/fawning to provide hinds/does with adequate space, safe shelters for delivering their offspring and avoid disturbance to other calving hinds/fawning does, which could lead to the loss of calves/fawns.
6. Females should be placed in calving/fawning paddocks at last 7–10 days before the anticipated start of calving/fawning.
7. Regular exercise reduces the risk of parturition problems, therefore, hinds/does should be kept in paddocks with steep hills in the prenatal period.
8. Unfamiliar deer should not be placed in calving/fawning paddocks.
9. Primiparous females should be segregated from adult hinds/does.

Conclusions

The issues related to deer farming, addressed in this paper, indicate that deer farm management is a highly complex process. Both successful deer farming and the welfare of farmed deer are determined by biological and behavioral factors on the one hand, and by the breeder's knowledge, skills and ability to adequately respond to animals' needs on the other. Many important aspects of deer farming technology remain insufficiently explored, and the findings regarding livestock (cattle, sheep) farming cannot be directly extrapolated to deer farming.

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THE EFFECT OF DIETARY BIO-ALGINATE SUPPLEMENTATION OF THE GROWTH RATE AND BODY WEIGHTS OF COMMON PHEASANT (*PHASIANUS COLCHICUS*) CHICKS

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K e y w o r d s: pheasant, Biopolym, alginates, growth rate, body weight.

A b s t r a c t

The aim of this study was to determine the influence of bio-alginates on the growth rate of pheasant chicks. Two experiments were performed in pheasant chicks were administered the Biopolym supplement from 1 to 29 days of age (experiment 1) or from 1 to 36 days of age (experiment 2). The Biopolym supplement had a significant effect on the growth rate of pheasant chicks, the highest relative increase in the body weights of birds was observed between 1 and 8 days of age, and it reached 62.9% in birds fed Biopolym-supplemented diets vs. 37.5% in the control group ($P \leq 0.05$) in experiment 1, and 60.2% vs. 48.0%, respectively ($P \leq 0.05$) in experiment 2. The body weights of pheasants fed Biopolym-supplemented diets increased 6.6-fold vs. 5.7-fold in the control group in experiment 1, and the respective values noted in experiment 2 were 9.1-fold vs. 8.4-fold ($P \leq 0.05$).

WPŁYW DODATKU BIOALGINIANU NA TEMPO WZROSTU I MASĘ CIAŁA KURCZĄT BAŻANTA ZWYCZAJNEGO (*PHASIANUS COLCHICUS*)

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S ł o w a k l u c z o w e: bażant, Biopolym, alginiany, tempo wzrostu, masa ciała.

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Streszczenie

Celem badań było określenie wpływu suplementacji dodatkiem bioalginianu na tempo wzrostu kurcząt bażanta. Przeprowadzono dwa doświadczenia w warunkach produkcyjnych, w których podawano piskletom preparat Biopolym od 1. dnia życia do wieku 29 dni (doświadczenie 1.) lub do 36 dnia (doświadczenie 2.). Stwierdzono istotny wpływ dodatku preparatu na tempo wzrostu masy ciała piskląt. Względne tempo wzrostu masy ciała piskląt było największe w okresie od 1–8. dnia życia u ptaków żywionych z dodatkiem preparatu Biopolym w doświadczeniu 1. wynosiło 62,9% i 37.5% w grupie kontrolnej ($P \leq 0.05$), a w doświadczeniu 2. odpowiednio – 60.2 i 48.0% ($P \leq 0.05$). Masa ciała ptaków, którym podawano Biopolym w doświadczeniu 1., wzrosła 6,6-krotnie (z 19,7 g do 133,3 g), a w grupie kontrolnej 5,7-krotnie (z 19,8 g do 112,3 g), natomiast doświadczeniu 2. odpowiednio 9,1- (z 20,5 g do 171,1 g) i 8,4-krotnie (z 20,3 g do 180,5 g; $P \leq 0,05$).

Introduction

Common pheasants (*Phasianus colchicus*) are raised commercially for meat or for release in hunting preserves. Pheasant hunting is very popular in the Czech Republic, where it is deeply rooted in local tradition. As a result, the number of birds introduced to hunting areas has to be continuously increased (HOLÁ et al. 2015). The profitability of commercial pheasant farming is determined by numerous factors, including the number of chicks reared. The success of pheasant farming depends on environmental factors, including adequate nutrition and housing conditions, particularly in the early life stages of birds (NOWACZEWSKI and KONTECKA 2005).

An EU-wide ban on the use of antibiotics as growth promoters in animal feed entered into effect in 2006, which prompted the search for new, safe feed additives and dietary supplements that could replace antibiotics and help maintain production efficiency. Probiotics, prebiotics, enzymes, oligosaccharides, organic acids and selected herbal extracts are considered to be a viable alternative to growth-promoting antibiotics. Positive effects of probiotic compounds have been observed, among others, in chickens (PATTERSON and BURKHODER 2003, ECKERT el al. 2010). Lactobacillus-based probiotics and prebiotic preparations are involved in beneficial modulation of gut microbiota in poultry, thus enhancing the birds' resistance to intestinal infections (FULTON et al. 2002). Probiotics and prebiotics can be used to prevent infections in poultry (LUTFUL KABIR 2009), but their therapeutic benefits are limited (EHRMANN et al. 2002).

Algae are also regarded as effective and safe feed additives, posing no risk to animal or human health. Microalgae, macroalgae and their products – alginates are used in plant production (HANZAL et al. 2015) and animal nutrition. Alginates are polysaccharides derived from marine algae, mainly brown algae (*Phaeophyceae*). They can also be synthesized extracellularly by bacteria such as *Azotobacter vinelandii*, *Pseudomonas aeruginosa* and *Pseudomonas fluor-*

escens (HOLTE et al. 2003, PEREIRA et al. 2003). One of the most common species of brown algae is *Ascophyllum nodosum,* harvested commercially on the coasts of Canada, Island and Northern Scotland. Algal preparations are widely used as feed supplements for livestock. In Canada, a commercial A. nodosum animal feed supplement is distributed under the brand name Tasco. The product has been found to improve feed efficiency and boost the immune system of animals. Results study BACH et al. (2008), indicate that 2% Tasco-14 supplementation in feedlot cattle diets reduces *Escherichia coli* (EHEC O157 and EHEC O157:H7) prevalence on hide swabs and in fecal samples and may suppress increases in *Salmonella spp*. Tasco© has been studied to determine effects on ability to increase reproductive traits in cattle and goats (YATES et al. 2010) and horses (WILLIAMS et al. 2015). Another algal preparation used as a feed additive is Biopolym. Biopolym, a hydrolysate of the brown alga A. nodosum, can be administered with solid feed or in liquid form (brand name: Biopolym FZT). Research has shown that Biopolym exerts a beneficial influence on gut microbiota, it improves digestion and accelerates nutrient absorption into the bloodstream, which increases feed conversion efficiency and body weight gains (GJUROV et al. 2007). Biopolym contains vitamins, amino acids, alginic acid in the form of sodium alginate E401, iodine and other trace elements. Due to its rich chemical composition, Biopolym contributes to cell regeneration, improves the health status and overall body condition of animals and helps reduce the mortality rates of young animals (HANZAL 2006, VOSTOUPAL et al. 2005).

Pheasant breeders also have to find effective alternatives to antibiotic growth promoters. The performance of farmed pheasants should be improved, particularly in early growth stages. The positive effects of dietary supplementation with bio-alginates, noted in other animal species, have prompted us to conduct the present study which investigated the influence of the Biopolym supplement on the growth rate of pheasant chicks.

Materials and Methods

The experimental materials comprised common pheasant (*Phasianus colchicus*) chicks. Two preliminary experiments were performed in the pheasantry located in Luhy near Chlumce in Eastern Bohemia (Czech Republic). In experiment 1, pheasant chicks were administered the Biopolym supplement (hydrolyzate) from 1 to 29 days of age, in experiment 2, from 1 to 36 days of age (control and experimental group of 120 birds each; 4 replicates of 30 birds), both groups were fed *ad libitum* commercial diets: 1–21 d; 29% total protein and 11.3 MJ (2700 kcal kg^{-1}) ME and 22 -36 d; 23% total protein and 11.7 MJ (2800 kcal kg^{-1}) ME.

The Biopolym supplement was mixed with drinking water (1ml/day/30 birds). All chicks were weighed individually on the first day of age and next at seven-day intervals.

In both experiments, pheasants were kept in the same hall with ventilation through windows and passive chimney fans. Lighting and thermal conditions were identical. An infrared heater was used during the first days of chicks' life. The birds were placed in the breeder house immediately after hatching.
Symbols:

– experiment 1: 1*C* – control group, no dietary Biopolym supplementation, 1*B* – experimental group, diets supplemented with Biopolym;

– experiment 2: 2*C* – control group, no dietary Biopolym supplementation, 2*B* – experimental group, diets supplemented with Biopolym.

The growth rate of pheasant chicks was calculated from the following formula:

$$\text{gr} = \frac{w_2 - w_1}{0.5x(w_1 + w_2) \cdot 100}$$

where:
gr – growth rate [%]
w_1 – BW at the beginning of the rearing period
w_2 – BW at the end of the rearing period.

The experiment was approved by the Local Ethics Committee at the University of South Bohemia in Ceske Budejovice.

The statistical analysis included the characteristics of the analysed traits – arithmetic means ($\bar{x}$) and standard deviations (SD) and the determination of the significance of differences in mean values between age groups, by Duncan's D test. The data were analysed by two-way ANOVA. The results were processed in the Statistica 2011 application (StatSoft Inc. 2011), at a significance level of 0.05.

Results

The Biopolym supplement had a significant effect on the growth rate of pheasant chicks (Figure 1). The highest relative increase in the body weights of birds fed Biopolym-supplemented diets (group 1*B*) was observed between 1 and 8 days of age, and it reached 62.9% vs. 37.5% in control group 1*C* ($P \leq 0.05$, Figure 1). At the next stage of the study (days 8–15), an interaction was noted: the growth rate of control group (1*C*) birds increased significantly to 64.7%, as compared with 52.4% in experimental group 1*B* ($P \leq 0.05$).

Between days 15–22 and 22–29, the growth rate of birds decreased gradually in both groups, but the noted decrease was smaller in experimental group 1*B* than in control group 1*C* (days 15–22: 1*B* – 41.9%, 1*C* – 35.7%, days 22–29: 1*B* – 32.7%, 1*C* – 29.1%, a statistically not significant difference). The age of birds and dietary supplementation with Biopolym had a significant influence on the body weights of pheasant chicks. The body weights of one-day-old birds from the control group (1*C*) and the experimental group (1*B*) were similar at 19.7 g and 19.8 g, respectively (Figure 2). At 29 days of age, the average body weight of

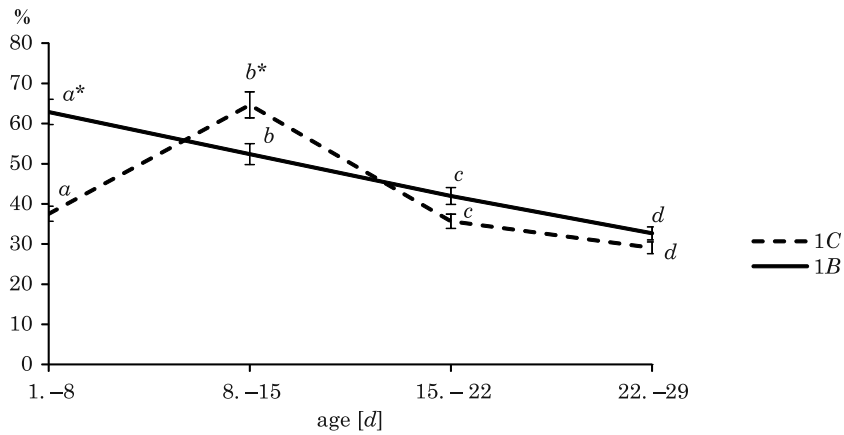

Fig. 1. Experiment 1. The growth rate of common pheasant chicks from 1 to 29 days of age [%; $\bar{x} \pm$ SD]. Values followed by different letters (age) or * (1*C* – control group, 1*B* – "Biopolym" group) differ significantly ($\alpha = 0.05$)

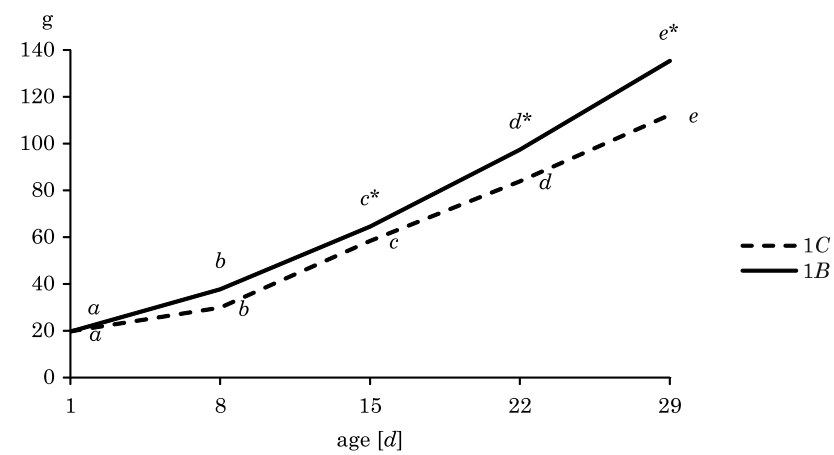

Fig. 2. Experiment 1. Average body weights of common pheasant chicks from 1 to 29 days of age [g; $\bar{x} \pm$ SD]. Values followed by different letters (age) or * (1*C* – control group, 1*B* – "Biopolym" group) differ significantly ($\alpha = 0.05$)

experimental group birds (1*B*; 133.3 g) was significantly higher than the average body weight of control group birds (1C: 112.3 g; $P \leq 0.05$, Figure 2). A significant effect of Biopolym on the body weights of pheasants was noted day 8 – 37.7 g in experimental group 1*B* vs. 28.9 g in control group 1*C* ($P \leq 0.05$). The beneficial influence of the analyzed supplement was observed until the end of the experiment, and the age x feeding interaction was noted in week 2. In this age group, no differences in body weight were found between control (1*C*) and experimental (1*B*) birds (Figure 2).

In experiment 2, Biopolym was administered to pheasant chicks aged 1 to 36 days. The differences in the growth rate of birds from experimental group 2*B* and control group 2*C* were similar to those noted in experiment 1. In both groups, the growth rate of birds decreased gradually with age ($P \leq 0.05$, Figure 3). Between 1 and 8 days of age, the growth rate of pheasant chicks that received the analyzed supplement (group 2*B*) reached 60.2%, and it was significantly higher than the growth rate of control group birds (2*C*; 48.0%; $P \leq 0.05$, Figure 3). In successive stages of the study, no differences in growth rate values were found between experimental (2*B*) and control (2*C*) birds. The Biopolym supplement had a significant effect on the body weights of pheasant chicks. The body weights of one-day-old birds from the control group (2*C*) and the experimental group (2*B*) were similar at 20.5 g and 20.3 g, respectively. At 36 days of age, the body weights of birds reached 185.0 g in the experimental group fed Biopolym-supplemented diets and 171.0 g in the control group ($P \leq 0.05$, Figure 4). The differences in the body weights of control and experimental birds were observed at 8 days of age, and were maintained until the end of the experiment.

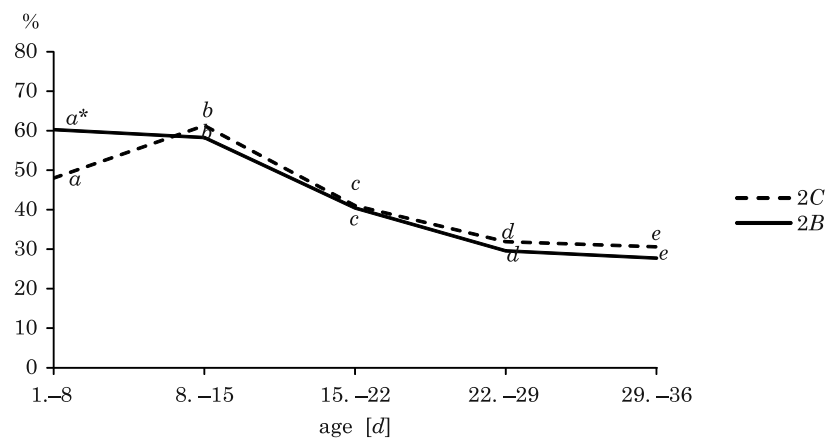

Fig. 3. Experiment 2. The growth rate of common pheasant chicks from 1 to 36 days of age [%; $\bar{x} \pm SD$]. Values followed by different letters (age) or * (2*C* – control group, 2*B* – "Biopolym" group) differ significantly ($\alpha = 0.05$)

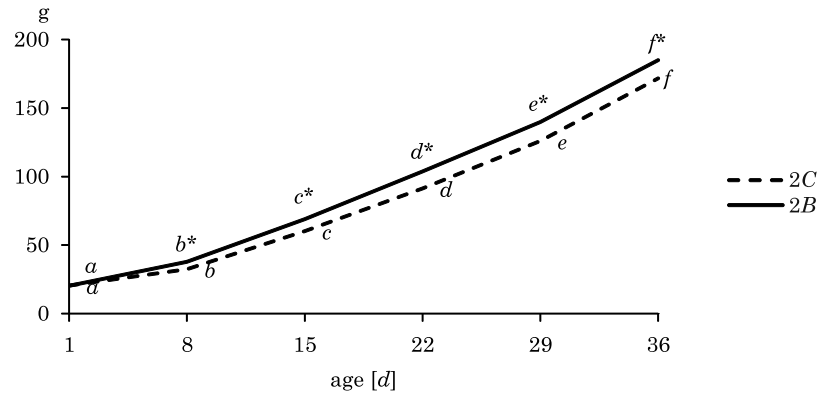

Fig. 4. Experiment 2. Average body weights of common pheasant chicks from 1 to 36 days of age [g; $\bar{x} \pm$ SD]. Values followed by different letters (age) or * (2*C* – control group, 2*B* – "Biopolym" group) differ significantly ($\alpha = 0.05$)

Discussion

Full expression of the genetic potential of farm-raised birds is largely dependent on the optimization of environmental conditions, including dietary modifications (HAVENSTEIN 2006). The effect of the dietary inclusion of Biopolym on performance and health status has been investigated in various livestock species. In contrast to the results of BACH et al. (2008), Biopolym did not produce the expected positive results in cattle (PETRÁŠKOVÁ et al. 2012), whereas it exerted a beneficial influence on the performance of pigs and broiler chickens (CERMAK et al. 2010). CERMAK et al. (2010) demonstrated that Biopolym increased body weight gains and improved feed efficiency in pigs, and reduced the mortality rates of broiler chickens. In a study by ZHANG et al. (2014), alginate-whey protein dry powder improved intestinal absorption in chickens and, in consequence, improved their performance.

An increase in body weight may vary in response to changing environmental conditions. In the present study, the Biopolym supplement had a significant effect on the growth rate of pheasant chicks in early life stages. Both in experiment 1 (dietary supplementation with Biopolym for 29 days) and experiment 2 (dietary supplementation with Biopolym for 36 days), birds fed Biopolym-supplemented diets were characterized by a considerably higher growth rate between days 1 and 8. The differences between control and experimental groups reached 22.1% in experiment 1 and 12.3% in experiment 2 (Figure 1 and Figure 3, respectively). It should be stressed that in both experiments, the growth rate of experimental group birds remained high also in the following week. The Biopolym supplement had no significant influence on the growth rate of pheasants older than 15 days of age. The high growth

rate of birds observed in early life stages led to increased body weights in successive weeks. The higher growth rate of pheasant chicks fed Biopolym-supplemented diets, noted in our study, resulted most probably from a positive effect of the analyzed feed additive on the gut microbiota of birds (VOSTOUPAL et al. 2005, SCHULZE and HERMSEN 2002, ZÁBRANSKÝ et al. 2014). The body weights of pheasants receiving Biopolym increased 6.6-fold vs. 5.7-fold in the control group in experiment 1, and the respective values noted in experiment 2 were 9.1-fold vs. 8.4-fold (Figure 2 and Figure 4, respectively).

The results of this preliminary study indicate that diets fed to farmed pheasants can be supplemented with Biopolym to improve bird performance and productivity. The dietary inclusion of Biopolym contributed to a faster growth rate of pheasant chicks in early life stages, followed by an increase in their body weights, which is a good indicator of bird condition.

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THE OCCURRENCE AND SOURCES OF POLYCYCLIC AROMATIC HYDROCARBONS IN BOTTOM SEDIMENTS OF THE WISŁOK RIVER

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K e y w o r d s: bottom sediments, Wisłok river, micro-contaminants, PAHs, contamination sources.

A b s t r a c t

The work presents analysis and assessment of the degree contamination of bottom sediments of the Wisłok river with polycyclic aromatic hydrocarbons (PAHs). The samples of the bottom sediments were taken in the summer in 2012 in 6 research points by Environmental Authorities under the State Monitoring for Environment. The concentration of the sum of 17 PAHs in the bottom sediments ranged from 0.218–8.437 mg kg^{-1} of dry weight. Among PAHs surveyed, 4-ring congeners had the largest share, and 3-ring ones had the smallest share. The highest concentration was registered in the case of fluoranthene, also four-cyclic benzo(a)anthracene and pyrene had a large share. Whereas the lowest concentration was registered for acenaphthene, acenaphthylene and fluorene. The work also identifies possible sources of PAHs in the bottom sediments analysed. The method used to identify the source of origin of PAHs in bottom sediments is comparison of the quotient of concentrations of compounds characterised by L/H low and high molecular masses and comparison of measured concentrations of analysed PAHs, e.g. Phe/Ant, Flt/Py, Flt/(Flt+Py), Ant/(Ant+Phe) as well as IndP/(IndP+BghiP). The values of indicators used for this purpose indicated contamination with compounds from the PAHs group of pyrolytic origin.

WYSTĘPOWANIE WIELOPIERŚCIENIOWYCH WĘGLOWODORÓW AROMATYCZNYCH W OSADACH DENNYCH RZEKI WISŁOK

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S ł o w a k l u c z o w e: osady denne, rzeka Wisłok, mikrozanieczyszczenia, WWA, źródła zanieczyszczeń.

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Abstrakt

W pracy przedstawiono analizę i ocenę stopnia zanieczyszczenia osadów dennych rzeki Wisłok wielopierścieniowymi węglowodorami aromatycznymi (WWA). Próbki osadów dennych pobrała w sezonie letnim w 2012 r. w 6 punktach badawczych Inspekcja Ochrony Środowiska w ramach Państwowego Monitoringu Środowiska. Stężenie sumy 17 WWA w osadach dennych wynosiło 0,218–8,437 mg kg^{-1} s.m. Wśród badanych WWA największy udział miały kongenery 4-pierścieniowe, najmniejszy 3-pierścieniowe. Najwyższe stężenie odnotowano w przypadku fluorantenu, duży udział miał także czteropierścieniowy benzo(a)antracen i piren. Najniższe stężenie odnotowano natomiast dla acenaftenu, acenaftylenu i fluorenu. W pracy zidentyfikowano również prawdopodobne źródła WWA w analizowanych osadach dennych. Metodą stosowaną do określenia źródła pochodzenia WWA w osadach dennych jest porównanie ilorazu stężeń związków charakteryzujących się małymi i dużymi masami cząsteczkowymi L/H oraz porównanie oznaczonych stężeń analizowanych WWA, np. Fen/Ant, Flu/Pir, Flu/(Flu+Pir), Ant/(Ant+Fen) oraz IndP/(IndP+Bper). Wartości wykorzystanych w tym celu wskaźników wskazały na zanieczyszczenia związkami z grupy WWA pochodzenia pirolitycznego.

Introduction

Bottom sediments constitute an important, dynamic and integral part of the water ecosystem. Return reactions occur between bottom sediments and water, and the character of exchange of organic substances, mineral substances, and gases is highly complicated. Above all it is a result of participation of a number of opposing or overlapping biological and physicochemical processes which are divided most generally into the processes that decide on precipitating components from water into the bottom sediment (sedimentation, physicochemical and biochemical precipitating dissolved and colloidal compounds from water, sorption of ions from water through the sediment sorptive complex) and the processes that cause substances to penetrate from the bottom sediment to water (dissolving sediment components and diffusion to water, desorption, mineralization of sediments organic components, etc.) (STARMACH et al. 1976, HELIOS-RYBICKA and ALEKSANDER-KWATERCZAK 2009).

As a consequence of that, the bottom sediments enable to keep trace of transformations which occur in the environment, and also to supply enough relevant information on the causes of these changes. On account of higher concentrations of organic contaminants in the bottom sediments, by comparison with their content in water, the bottom sediments chemical analysis enables to detect and observe changes in their contents even with a relatively low degree of environmental pollution (GAWLIK and BILEK 2006, SZLACHTA 2009).

Among organic contaminants of water ecosystems, polycyclic aromatic hydrocarbons constitute a significant group. PAHs are compounds formed in biosynthesis processes, nevertheless to a large extent they are a result of human activity, mainly of incomplete combustion processes. Smelting and coking industry, combined heat and power plants, waste incineration plants,

farms, rubber, carbon electrodes production plants, car engines are the centre of their emission to the atmosphere. PAHs settle the most often on surfaces of soot particles, and then they fall directly on soil and water surfaces. Apart from that, they get into water bodies together with surface flows from contaminated areas. Areas in the immediate vicinity of industrial plants, roads and combined heat and power plants are exposed the most (SAPOTA 2002, KALETA 2005, KOCIOŁEK-BALAWEJDER and STANISŁAWSKA 2012, WŁODARCZYK-MAKUŁA 2014). Generally sources of PAHs may be divided into pyrogenic ones-connected mainly with combustion processes and petrogenic sources, connected with petroleum and its products penetrating into the environment (WOLSKA et al. 2014).

The tool used to identify the source of origin of compounds from the PAHs group in bottom sediments is comparison of the concentrations of compounds with low and high molecular masses and analysis of the quotients of concentrations of selected PAH (ROGOWSKA et al. 2013).

The purpose of the work was to determine the degree of contamination with compounds from the PAHs group and to identify the sources of their origin in the bottom sediments of the Wisłok river.

Survey Area

The area where the samples to be analysed were taken was the Wisłok river, located in the south-eastern part of Poland. The Wisłok river is a typically mountain river, classified into changeless and average rivers, according to the classification by length and continuity of their feed. It is a left-bank tributary of the San river with the length of 220 km and the river basin of 3,528 km^2. The sources of the Wisłok river are located in Beskid Niski, in the vicinity of the Slovak border. In the region of Rzeszów, it flows into Pradolina Podkarpacka, being distinguished by a dense waterway network and wide areas of wetlands (KOSZELNIK et al. 2004, MADEYSKI et al. 2008, SANOCKA and WIŚNIOS 2012).

The samples of bottom sediments were taken from 6 research points: 1st sampling point – Boguchwała, 2^{nd} – Besko, 3^{rd} – Wojaszówka, 4^{th} – Czarna, 5^{th} – Tryńcza, 6^{th} – Zarszyn.

Survey Scope and Methodology

Surveys of the contents of polycyclic aromatic hydrocarbons in the bottom sediments of the Wisłok river were conducted by the Environmental Authorities under the State Monitoring for Environment. Samples of the bottom

sediments were taken in the summer in 2012 in 6 research points. The scope of the bottom sediments surveys conducted included determination of concentrations of 17 PAHs congeners with the use of gas chromatography coupled with mass spectrometry, by applying an internal method of the State Inspectorate for Environmental Protection.

Until 2012, in Poland there was only one legal act on the quality of sediments. It was the Ordinance of the Minister for the Environment (OME) of 16 April 2002 on types and concentrations which cause output contamination (Rozporządzenie Ministra Środowiska z 16 kwietnia 2002 r... Dz.U. no. 55, item 498). Currently, since 2013 surveys in the subsystem of Monitoring of bottom sediments have been conducted based on only eco-toxicological criteria for organic compounds and geochemical ones for metals.

Contaminants threshold contents – lower TEL (Threshold Effect Level) and upper PEL (Probable Effects Levels) as well as PEC (Predicted Environmental Concentration) values – are used to assess a negative effect of polycyclic aromatic hydrocarbons contained in the sediments on water organisms. The PEC value is treated as a predicted concentration in the water environment. The TEL level corresponds to the content of a chemical element or compound

Table 1
Acceptable contents of PAHs in bottom sediments, based on (*Stan środowiska...* 2009, Rosińska 2010, Rosińska and Dąbrowska 2011)

PAHs	Concentration [mg kg^{-1} dw]			
	OME	TEL	PEL	PEC
Acenaphthene	–	0.00671	0.089	–
Acenaphthylene	–	0.00587	0.128	–
Anthracene	–	0.0469	0.245	0.845
Fluorene	–	0.0212	0.144	0.536
Phenanthrene	–	0.0867	0.544	1.170
Fluoranthene	–	0.113	1.494	2.23
Chrysene	–	0.108	0.862	1.29
Pyrene	–	0.153	0.875	1.5120
Benzo(a)anthracene	≥ 1.5	0.0748	0.385	1.05
Benzo(b)fluoranthene	≥ 1.5	–	–	–
Benzo(k)fluoranthene	≥ 1.5	–	–	–
Benzo(g.h.i)perylene	≥ 1.0	–	–	–
Benzo(a)pyrene	≥ 1.0	0.032	0.782	1.45
Dibenzo(a.h)anthracene	≥ 1.0	0.00622	0.135	–
Indeno[1.2.3–cd]pyrene	≥ 1.0	–	–	–
Σ PAHs	–	–	5.683	22.80

below which the contaminants toxic effect occurs rarely, whereas with values above PEL a harmful effect on the organisms is often observed (Table 1) (*Stan środowiska*... 2009, ROSIŃSKA 2010, ROSIŃSKA and DĄBROWSKA 2011).

Results of the Surveys and Discussion

The concentrations of 17 detected congeners of polycyclic aromatic hydrocarbons (PAHs) and their sums in the bottom sediments of the Wisłok river are presented in Table 2.

Table 2

The concentrations of the PAHs (mg kg^{-1} dw) in the bottom sediments from the Wisłok river in 2012

PAHs		Research points						Mean
		1	2	3	4	5	6	
Acenaphthene	Ace	0.003	0.005	0.007	0.0005	0.003	0.007	0.0043
Acenaphthylene	Acft	0.004	0.006	0.012	0.0005	0.0005	0.018	0.0068
Anthracene	Ant	0.032	0.078	0.126	0.001	0.008	0.058	0.0505
Benzo(a)anthracene	BaA	0.213	0.414	0.722	0.015	0.08	0.389	0.3055
Benzo(a)pyrene	BaP	0.227	0.424	0.712	0.02	0.105	0.549	0.3395
Benzo(b)fluoranthene	BbF	0.26	0.415	0.71	0.025	0.134	0.634	0.363
Benzo(e)pyrene	BeP	0.18	0.3	0.503	0.019	0.099	0.483	0.264
Benzo(k)fluoranthene	BkF	0.121	0.223	0.382	0.011	0.057	0.282	0.1793
Benzo(g.h.i)perylene	BghiP	0.175	0.309	0.505	0.019	0.107	0.483	0.2663
Chrysene	Chry	0.195	0.374	0.656	0.016	0.08	0.398	0.2865
Dibenzo(a.h)anthracene	DBA	0.039	0.078	0.124	0.0025	0.023	0.105	0.0619
Fhenanthrene	Phe	0.117	0.223	0.459	0.006	0.025	0.292	0.187
Fluorene	Fluo	0.006	0.011	0.023	0.0005	0.002	0.035	0.0129
Fluoranthene	Flt	0.392	0.769	1.472	0.028	0.135	0.684	0.58
Iindeno[1.2.3-cd]pyrene	InP	0.172	0.309	0.508	0.018	0.105	0.457	0.2615
Perylene	Per	0.115	0.162	0.259	0.012	0.062	0.24	0.1417
Pyrene	Py	0.333	0.651	1.257	0.024	0.121	0.609	0.4992
Σ 17 PAHs		2.584	4.751	8.437	0.218	1.1465	5.723	3.8099

The bottom sediments taken from 6 research points were highly diversified in terms of the content of polycyclic aromatic hydrocarbons. The concentration of the sum of 17 PAHs in bottom sediments ranged from 0.218–8.437 mg kg^{-1} of dry weight. The PAHs compounds contamination was the lowest in the point located in the town Czarna, where in most forests and wastelands occur, and the highest in Wojaszówka – mainly agricultural lands.

One can assess the degree of bottom sediment contamination based on the concentration of 16 priority PAH, determined by USEPA. Sediments may be

classified as heavily contaminated when the concentration of Σ16 PAHs is above 0.5 mg kg^{-1} of dry weight, moderately contaminated when this concentration is from 0.25 to 0.5 mg kg^{-1} of dry weight and weakly contaminated when the concentration monitored is below 0.25 mg kg^{-1} of dry weight. Except for the point located in Czarna (about 0.218 mg kg^{-1} of dry weight), according to this division the sediments surveyed may be classified as heavily contaminated (GUO et al. 2009). Nevertheless relating to the classification of the level of contamination of sediments by PAHs (low level: 0–0.1 mg kg^{-1} of dry weight, moderate level: 0.1–1 mg kg^{-1} of dry weight, high level: 1–5 mg kg^{-1} of dry weight and very high level: > 5 mg kg^{-1} of dry weight) proposed by BAUMARD et al. (1998), the bottom sediments surveyed are characterised by a changeable level, from the moderate one to the very high level of PAHs contaminants.

Analogous scopes of concentrations of the sum of PAH in bottom sediments were registered in the San river. The content of polycyclic aromatic hydrocarbons in 1995, 1998 and 2009–2014 ranged from < 1 mg kg^{-1} to over 11 mg kg^{-1}. When analysing the results of the surveys of bottom sediments conducted in the area of West Pomeranian Voivodeship under the State Monitoring for Environment in 2010–2011, diversified levels of contamination with PAHs compounds were also shown. The content of the sum of 17 PAHs in the surveyed sediments of rivers in the area of this Voivodeship was from 0.0655 to 9.2050 mg kg^{-1} of dry weight. An increased concentration of the sum of 17 PAHs was observed in the bottom sediments of the Wieprza river in Stary Kraków and of the Odra river in Gryfin. A maximum concentration was registered in 2011 in the Dzierżęcinka river in Koszalin. Whereas the content of 17 PAHs in the surveyed sediments of lakes was higher than in the bottom sediments of rivers and was from 0.076 to 21.375 mg kg^{-1} of dry weight. An increased content of PAHs compounds was observed in the Wielke Dąbie, Morzycko, Starzyc and Trzesiecko lakes. Furthermore, concentration values exceeding even 100 mg kg^{-1} of dry weight were registered in the bottom sediments of the Odra and Przemsza rivers [Report on the environmental situation 2010–2011, Bojakowska 2006]. Nonetheless, relating to literature data on the degree of contamination of bottom sediments of rivers located in other countries, considerable diversification in the contents of polycyclic aromatic hydrocarbons is observed. For example, the concentration of the sum of 16 PAHs in bottom sediments in Italy was within the range from 0.92 to 279.38 mg kg^{-1} of dry weight (PERRA et al. 2009). Whereas in the Kor river in Iran within the range of 167.4–530.3 mg kg^{-1} of dry weight (KAFILZADEH et al. 2011).

Among the PAHs surveyed, the highest concentration was observed in the case of fluoranthene (0.028–1.472 mg kg^{-1} of dry weight), four-cyclic benz(a)anthracene and pyrene, and also five-cyclic benzo(b)fluoranthene and ben-

zo(a)pyrene also have a large share. Whereas the lowest concentration was registered for acenaphthene, acenaphthylene and fluorene (Figure 1). Nonetheless, among polycyclic aromatic hydrocarbons it is the presence of benzo(a)pyrene (BaP) which has the strongest effect on the quality of bottom sediments, mainly because of high toxicity. Furthermore, BaP being identified in any element of the environment shows share in it of also other compounds from this group. The concentration of benzo(a)pyrene in the taken samples of bottom sediments was within the range of 0.02–0.712 mg kg^{-1} of dry weight and exceeded neither the PEL, PEC threshold values, nor the values determined by the Ordinance of the Minister for the Environment of 16 April 2002 on types and concentrations of substances which cause output contamination (Rozporzadzenie Ministra Środowiska z 16 kwietnia 2002 r. Dz.U no. 55, item 498). However, these values exceeded the TEL threshold value (0.032 mg kg^{-1} of dry weight). Exception was the bottom sediments taken from Czarna, where the concentration of BaP in bottom sediments was 0.02 mg kg^{-1} of dry weight. In the same year an average concentration of this compound of 150 Polish lakes was several times higher by comparison with the bottom sediments of the Wisłok river (BOJAKOWSKA et al. 20120).

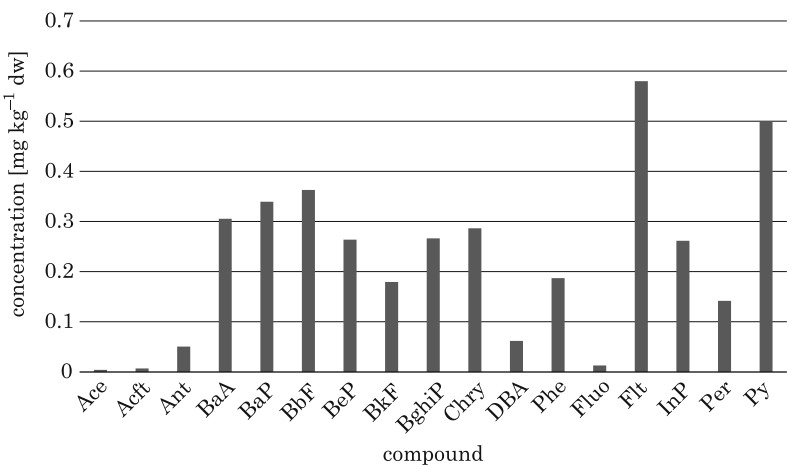

Fig. 1. The mean concentrations of PAHs in the bottom sediments in the Wisłok river in 2012

Depending on the number of aromatic rings, PAHs are divided into four groups: 3-, 4-, 5- and 6-ring. Average shares of the individual groups of compounds are presented in Figure 2. Four-ring PAHs (44%) have the largest share, then 5-ring ones (35%), 3-ring compounds (7%) had the smallest share.

Difference in the share of individual groups of PAHs is apparently a result of their dissimilar susceptibility to decomposition by micro-organisms, which is

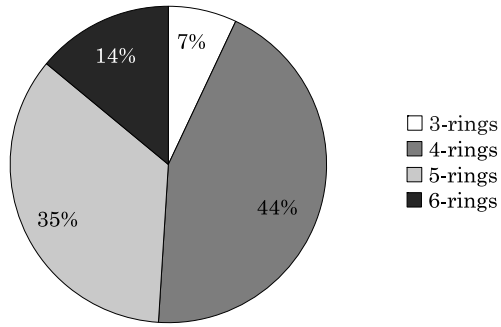

Fig. 2. The percentage of individual groups of compounds of PAHs in the bottom sediments in 2012 depending on the number of rings in the molecule

strictly connected with the number of rings in molecules of individual congeners. PAHs with lower molecular masses, such as naphthalene and phenanthrene, are quickly degraded in bottom sediments, whereas compounds with the higher number of rings, such as pyrene, fluoranthene, benzo(a) anthracene and benzo(a)pyrene are more resistant to biodegradation (OBAYORI and SALAM 20100. The diversified contents of individual groups of PAHs are also connected with the (K_{ow}) octanol/water distribution coefficient. The solubility of polycyclic aromatic hydrocarbons decreases with the increase in molecular mass, and therefore with the increase in the K_{ow} coefficient. As a consequence of that, compounds with greater molecular mass settle on constant molecules which, in turn, involves greater concentration of them in bottom sediments (DJOMO et al. 1996).

The presence of polycyclic aromatic hydrocarbons in the environment is a result of different processes, both natural, and anthropogenic ones. The main source of PAHs in the environment are combustion processes – pyrogenic sources, e.g. combustion of fossil fuels, forest fires, grass and bush burning as well as contamination with petroleum and its products – petrogenic sources. These compounds penetrate into the water environment as a result of dry or wet deposition. The share of treated sewage being introduced to waters directly from sewage-treatment plants is still unspecified (WOLSKA et al. 2014, ROGOWSKA et al. 2013). The method used to identify the source of origin of compounds from the PAH group in bottom sediments is comparison of the quotient of concentrations of compounds characterised by low and high molecular masses and comparison of the measured concentrations of analysed PAHs. The concentrations ratio of selected polycyclic aromatic hydrocarbons may indicate the source of emission and the environmental fate prior to depositing them in bottom sediments (ROGOWSKA et al. 2013).

PAH with the higher number of aromatic rings are considered to be technogenic character contaminants, whereas 2- and 3-cyclic ones belong to natural origin substances. The ratio of the sum of PAHs with low molecular mass (L), to which 2- and 3- cyclic compounds belong, to the sum of PAHs with high molecular mass (4-6 rings) was calculated for all samples. The L/H value < 1 indicates PAH compounds contamination of pyrolytic origin (MAGI et al. 2002). The L/H indicator values of the surveyed bottom sediments for all points are lower than 1 and are within the range from 0.035 to 0.080 (Figure 3). Possible sources of emission of PAHs found in the bottom sediments of the Wisłok river are thus combustion processes. The L/H indicator lowest value was found in the point located in Tryńcza. Whereas, the largest L/H ratio was in Wojaszówka, where contamination with these compounds was the highest. The L/H indicator for PAHs may differ considerably depending on the season. For example, these compounds in winter occur in higher concentrations, it concerns both congeners with the lower, and higher number of rings. Nonetheless in the summer lower contents of 2- and 3- ring PAHs, which effortlessly escape from contaminated sediments due to lower boiling points, are observed (CHEN et al. 2012, GARCIA-FALCON et al. 2006). The samples of the surveyed bottom sediments of the Wisłok river were taken in July, therefore compounds containing 4-6 aromatic rings dominated in the bottom sediments surveyed.

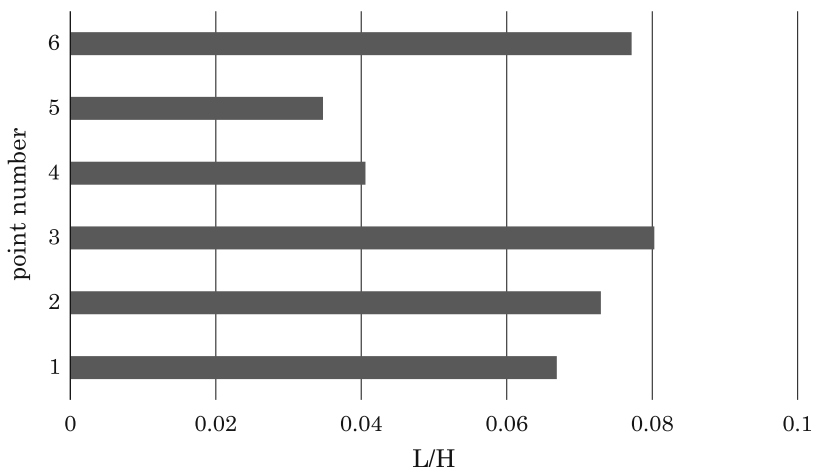

Fig. 3. The ratio L/H for individual research points

Another indicator used to identify sources of polycyclic aromatic hydrocarbons may also be the ratio of concentration of phenanthrene to anthracene (Phe/Ant) and fluoranthene to pyrene (Flt/Py). On the whole, PAHs of

petrogenic origin are characterised by the Phe/Ant ratio above 10, whereas for combustion processes Fen/Ant is < 10. In the case of the Flt/Py ratio, values greater than 1 indicate pyrolytic origin, and values lower than 1 – petrogenic origin (NEKHAVHAMBE et al. 2014). In the bottom sediments analysed, the values of the quotient of Phe/Ant concentrations were 3.66, 2.82, 3.64, 6.00, 3.13, 5.04, and the values of the Flt/Py indicator: 1.18, 1.18, 1.17, 1.17, 1.12, 1.12. The Phe/Ant and Flt/Py ratios suggest that PAH in the Wisłok river in all sampling points originate from pyrolytic sources (Figure 4).

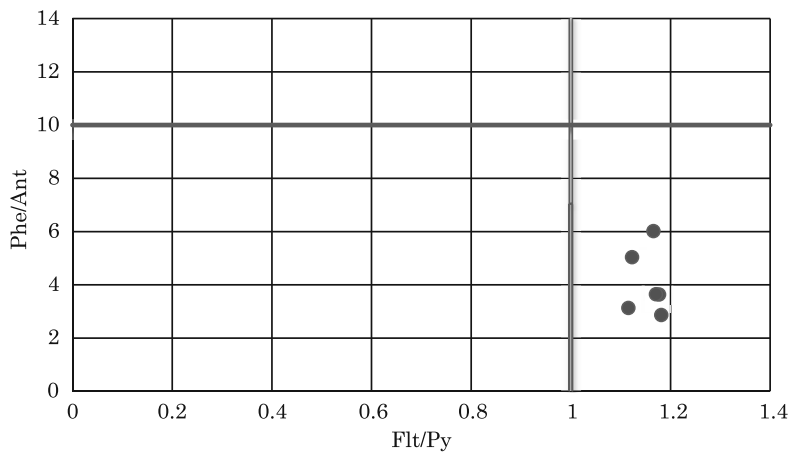

Fig. 4. Identification of sources of PAHs based on the ratio Phe/Ant and Flt/Py

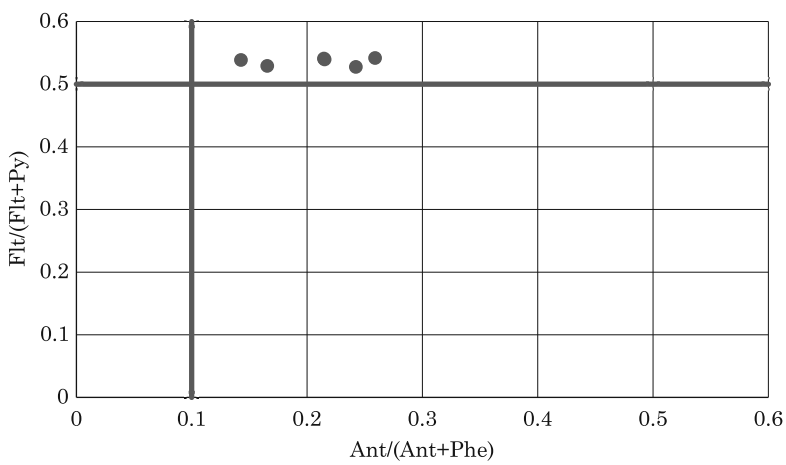

Fig. 5. Identification of sources of PAHs based on the ratio Flt/(Flt+Py) and An/(An+Phe)

The Flt/(Flt+Py) concentrations ratio may also be used to identify the origin of PAHs in the environment. The indicator with the value of > 0.5 is characteristic of grass, wood and coal burning, within the range from 0.4 to 0.5 characteristic of petroleum combustion and < 0.4 indicates petrogenic sources (YUNKER et al. 2002). This indicator confirms pyrolytic origin of PAHs contained in the bottom sediments of the Wisłok river (Figure 5). Furthermore, based on the Ant/(Ant+Phe) and IndP/(IndP+BghiP) indicators, the sources of PAH may be classified into the pyrolytic sources (Figure 5 and Figure 6). It is proved by the Ant/(Ant+Phe) concentrations ratio > the value of 0.1 and IndP/(IndP+BghiP) being within the range from 0.2 to 0.5.

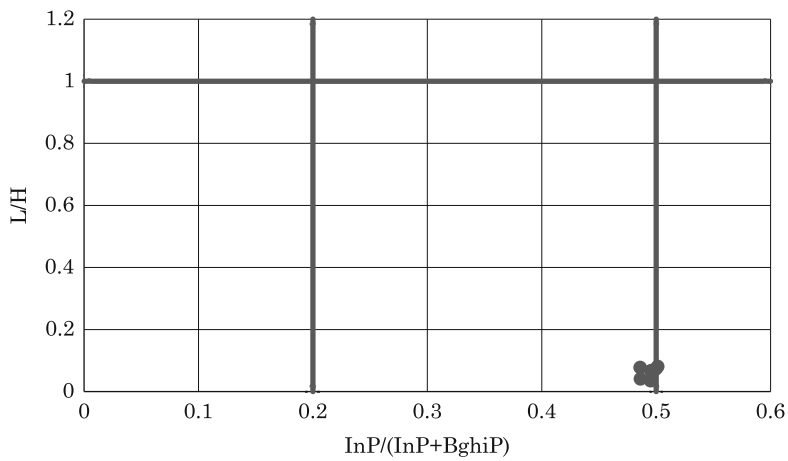

Fig. 6. Identification of sources of PAHs based on the ratio L/H and InP/(InP+BghiP)

Conclusions

As a result of the surveys conducted, the following conclusions were drawn:

1. The content of the sum of 17 measured PAHs in the surveyed bottom sediments in 2012 was within the range from 0.218 to 8.437 mg kg^{-1} of dry weight.

2. Exceeding the PEL threshold value for Σ WWA, indicating that bottom sediments often harmfully affecting the water organisms occur, was registered in the bottom deposits taken from Wojaszówka and Zarszyn. Whereas, exceeding the PEC value was not registered.

3. Fluoranthene (0.028–1.472 mg kg^{-1} of dry weight) dominated across the spectrum of measured PAHs, four-ring benz(a)anthracene and pyrene, and also five-ring benzo(b)fluoranthene and benzo(a)pyrene also had a large share.

Whereas the lowest concentration was registered for acenaphthene (0.0005–0.007 mg kg^{-1} of dry weight), acenaphthylene (0.0005–0.018 mg kg^{-1} of dry weight) and fluorene (0.0005–0.035 mg kg^{-1} of dry weight).

4. The concentration of benzo(a)pyrene in the samples of bottom sediments taken was within the range of 0.02–0.712 mg kg^{-1} of dry weight and exceeded neither the PEL, PEC threshold values, nor the values determined by the Ordinance of the Minister for the Environment of 16 April 2002 on types and concentrations of substances which cause output contamination (Rozporządzenie Ministra Środowiska z 16 kwietnia 2002 r... Dz.U no. 55, item 498).

5. Domestic and worldwide diversification in the occurrence of PAHs in bottom sediments was observed. The chemical composition of bottom sediments is a result not only of the land geomorphology and climatic conditions, but also of the manner lands along rivers are developed and used.

6. The concentrations ratio of selected PAHs may indicate the source of emission and the environmental fate prior to depositing them in bottom sediments.

7. The comparison of the quotient of concentrations of compounds characterised by L/H low and high molecular masses and the comparison of the measured concentrations of analysed PAH, e.g. Phe/Ant, Flt/Py, Flt/(Flt+Py), Ant/(Ant+Phe) and IndP/(IndP+BghiP) showed that the main source of PAHs in the bottom sediments of the Wisłok river are combustion processes (pyrogenic sources).

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IMPACT OF HIGH-PRESSURE HOMOGENIZATION PERFORMED AT DIFFERENT TEMPERATURES ON CHANGES IN SELECTED STABILITY PARAMETERS OF THE EMULSION AND COLLOIDAL PHASES OF MILK

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K e y w o r d s: high-pressure homogenization, milk, emulsion stability, size of fat globules, colloidal stability.

A b s t r a c t

The impact of high-pressure homogenization performed at a pressure of 120 MPa and temperature of 6, 20, 40, and 60°C and of conventional homogenization performed at a pressure of 20 MPa and temperature of 60°C on selected properties of milk normalized to a fat content of 3.5% was determined. The results of the research on the impact of high-pressure homogenization demonstrated increased fragmentation of fat globules and their surfaces, as well as reduced creaming, when there was an increase in the initial temperature of the milk. The size of fat globules in milk subjected to homogenization under conventional parameters was on the level between the size of fat globules in milk undergoing high-pressure homogenization at a temperature of 20°C and 40°C. Reduced heat stability and rennet coagulation time, as well as reduced temperature in the range of, respectively, 6–40°C and 6–60°C, were found. The analysed characteristics of the colloidal stability of milk undergoing high-pressure homogenization reached lower values compared to conventional homogenization.

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WPŁYW HOMOGENIZACJI WYSOKOCIŚNIENIOWEJ PRZEPROWADZONEJ W ZRÓŻNICOWANEJ TEMPERATURZE NA ZMIANY WYBRANYCH WYRÓŻNIKÓW STABILNOŚCI FAZ EMULSYJNEJ I KOLOIDALNEJ MLEKA

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S ł o w a k l u c z o w e: homogenizacja wysokociśnieniowa, mleko, stabilność emulsji, rozmiar kuleczek tłuszczowych, stabilność koloidalna.

A b s t r a k t

Określono wpływ homogenizacji wysokociśnieniowej, przeprowadzonej w ciśnieniu 120 MPa i temperaturze 6, 20, 40 i 60°C, oraz homogenizacji konwencjonalnej, w ciśnieniu 20 MPa i temperaturze 60°C, na wybrane cechy fizykochemiczne mleka znormalizowanego do zawartości tłuszczu 3,5%. Wykazano, że homogenizacja wysokociśnieniowa wpływała na zmniejszenie rozmiarów kuleczek tłuszczowych i wzrost pola ich powierzchni oraz obniżenie zdolności do śmietankowania wraz ze wzrostem temperatury początkowej mleka. Rozmiary kuleczek tłuszczowych w mleku poddanym homogenizacji w warunkach konwencjonalnych kształtowały się na poziomie rozmiaru kuleczek pomiędzy mlekiem poddanym homogenizacji wysokociśnieniowej przeprowadzonej w temperaturze 20 i 40°C. Stwierdzono obniżanie się stabilności cieplnej i czasu krzepnięcia podpuszczkowego wraz z obniżeniem temperatury w zakresie odpowiednio 6–40°C i 6–60°C. Analizowane wyróżniki stabilności koloidalnej mleka poddanego homogenizacji wysokociśnieniowej osiągały niższe wartości w porównaniu z homogenizacją konwencjonalną.

Introduction

Homogenization is a technological process performed in order to increase the stability of the emulsion by reducing and homogenizing the size of fat globules. In order to protect the product against creaming, conventional homogenization is commonly used, with a pressure ≤ 20 MPa and temperature ≥ 60°C. High-pressure homogenization, conducted at a pressure ≥ 100 MPa enables achieving a high dispersion of milk fat, improves the microbiological quality of the milk, whereby the desired effect can be achieved at temperatures < 60°C (HAYES and KELLY 2003, HAYES et al. 2005, PEREDA et al. 2007, THIEBAUD et al. 2003). An additional result of high-pressure homogenization is an increase in the temperature of the product in the course of the process (HAYES and KELLY 2003, PEREDA et al. 2007, SANDRA and DALGLEISH 2005, THIEBAUD et al. 2003) and inactivation of the native milk enzymes (alkaline phosphatase, peroxidase) to an extent that depends on the parameters of the process (HAYES et al. 2005, PEREDA et al. 2007). This process can be used as an alternative preservation method to pasteurization in the production of drink-

ing milk, replacing both pasteurization and conventional homogenization (HAYES et al. 2005, PEREDA et al. 2007). Nevertheless, the results of SMIDDY et al. (2007) indicate that preservation of milk using only high-pressure homogenization is insufficient to achieve the microbiological quality required and in the case of extended-shelf-life milk can be used in practice in combination with traditional thermal processing.

As a result of its impact on the increased scattering of fat globules, high-pressure homogenization contributes to adsorption of milk plasma proteins in an increasing fat-plasma inter-phase surface of milk (ZAMORA et al. 2012). Moreover, high-pressure homogenization of skim milk, using the example of reconstituted milk, results in a decrease in the sizes of the casein micelles and dissociation to the serum, as well as an increase in the quantity of the casein fractions κ, α_{s1} and α_{s2} in a non-sediment form (SANDRA and DALGLEISH 2005). The specificity of the colloidal phase changes determines the increase in the contents of the soluble calcium and phosphorus forms in skim and whole milk subjected to homogenization (KIEŁCZEWSKA et al. 2008). Besides of the numerous changes taking place as a result of the process the denaturation of whey proteins, mostly β-lactoglobulin and, to a lesser extent, α-lactalbulin also noted (PEREDA et al. 2009). The changes in the components of all phases of milk (emulsion, colloidal, molecular) induced as a result of high-pressure homogenization may contribute to the milk;s resistance to coagulating factors (high temperature, proteolytic enzymes).

The purpose of the research was to determine changes in selected characteristics of stability of the emulsion and colloidal phases, which are important from a practical perspective, taking place as a result of homogenization of milk at different temperatures.

Material and Methods

Material

The material used in the research was milk obtained from the University of Warmia and Mazury in Olsztyn (Olsztyn, Poland) farm, cooled to a temperature of $\leq 4^{o}$C, brought to a laboratory and preserved by adding 1 cm^3/1 dm^3 of a 2% sodium azide solution.

Before the homogenization process, the milk was normalized to a fat content of 3.5% and was reached to the homogenization temperature.

Homogenization process

High-pressure homogenization was performed at a constant pressure of 120 MPa and at different temperatures as follows 6°C, 20°C, 40°C and 60°C. Also, homogenization was performed at the pressure of 20 MPa, and temperature of 60°C. The milk temperature was measured before and after homogenization. The homogenization was performed using a Panda homogenizer (Gea Niro Soavi, Parma Italy). A control sample consisted of non-homogenized milk with fat content of 3.5%. The experiment was performed in six repetitions.

Size of fat globules

An evaluation of the level of dispersion of milk fat in the samples was conducted using the microscopic method with a set of devices consisting of an optical microscope (Carl Zeiss, Jena, Germany) (63x focus), a CCD Moticam Pro camera (Motic, Motic Asia, Hong Kong, China), and a monitor. An alcoholic solution of 2-naphthalenol,1-[2-[4-(2-phenyldiazenyl)phenyl]diazenyl] (Merck, Darmstadt, Germany) mixed with glycerine to a proportion of 1:1 was added to the milk samples intended to be used in the making of the microscope specimens (*Mleko, śmietanka...* PN-A-86059:1975). Based on microscopic images, the percentages of the fat globules of different size ranges were calculated. The measurement of the values of the milk fat dispersion was performed using a Mastersizer 3000 particle-size analyser (Malvern Instruments, Malvern, United Kingdom), using a Hydro EV accessory (Malvern Instruments, Malvern, United Kingdom), with obscuration in the range of 5–15, and refractive indexes of milk and water dispergent were 1.46 and 1.33, respectively. The milk samples to be tested were prepared by mixing them with an ethylenediaminetetraacetic acid disodium salt (Merck, Darmstadt, Germany) solution of a concentration 33 mmol L^{-1} in NaOH and with pH 7.0 (McCrae and Lepoetre 1996). The size of the fat globules, expressed as d_{32} (Sauter diameter), d_v10 and d_v50 (a diameter larger than the diameter of 10% and 50%, respectively, of the fat globules), and their specific surface area were determined.

Emulsion stability

The emulsion stability was evaluated by determining the content of the fat using the butyrometric method (*Mleko...* PN-ISO 2446:2010) in the top (10% of the volume) and bottom (90% of the volume) layers of milk stored in cylinders at a temperature of 4°C for 48 hours (Bylund 1995).

Colloidal stability

The heat stability was evaluated at the time of coagulation at a temperature of 140°C (KRUK et al. 1979). The rennet coagulation time (ALAIS and JOLLES 1964) was evaluated using the Chy-Max preparation (Chr. Hansen, Hørsholm, Denmark).

Statistical analysis

Data were presented as average values and their variability was expressed as a standard deviation. The Tukey's honest significance test was conducted with a significance level of $\alpha = 0.05$. Statistical analysis was performed using Statistica, v. 10.0, software by StatSoft (Tulsa, Oklahoma, USA).

Results and Discussion

The results demonstrated an increase in the temperature of the milk in the course of homogenization, the value of which depended on the initial temperature of the milk. The maximum increase of temperature, equal to approx. 29°C, or 2.45°C per 10 MPa, occurred in the case of homogenization of milk with an initial temperature of 6°C. Homogenization of milk at the other analysed temperatures resulted in smaller increases in temparature (Table 1). For milk with an initial temperature of 20°C, the process resulted in an increase in milk temperature of about 26°C, but at higher initial temperatures of 40°C and 60°C, homogenization caused an increase in milk temperature of about 15°C and 11°C, respectively. The results of the temperature measurements were partly confirmed by data published in relevant literature that mentions a temperature increase of 27°C for milk with an initial temperature equal to 6°C at a pressure of 100 MPa, whereby the higher the pressure, the larger the difference between the initial milk temperature and the final milk temperature (HAYES and KELLY 2003). THIEBAUD et al. (2003) demonstrated that in the case of high-pressure homogenization of milk with an initial temperature in the range of 4–24°C, its temperature after the process increased by approx. 16°C per 100 MPa. HAYES et al. (2005) noted an increase of 22°C in the temperature of milk homogenized at the initial temperature of 45°C and at the pressure of 150 MPa, whereby the higher the pressure of the process, the higher the milk temperature: the highest increase, equal to approx. 38°C, was noted at a pressure of 250 MPa. PEREDA et al. (2007), on the other hand, demonstrated an increase of approximately 20°C per each 100 MPa in the temperature of

milk homogenized at an initial temperature of 40°C and at a pressure in the range of 100–300 MPa.

Table 1

Parameters of high-pressure homogenization of milk

Pressure [MPa]	Temperature [°C]		
	initial	final	ambient
120	6[a]	35.4 ± 3.0[b]	16.2 ± 3.2
	20[a]	45.9 ± 3.0[b]	
	40[a]	55.2 ± 2.6[b]	
	60[a]	71.5 ± 2.4[b]	
20	60[a]	61.9 ± 2.7[a]	

$n = 6$; the values in the rows marked with the same letter show no significant differences at $\alpha = 0.05$

As a result of the observations and calculations, it was found that the sizes of the fat globules decreased with an increase in the initial temperature of the milk undergoing high-pressure homogenization. In milk undergoing high--pressure homogenization at the initial temperatures of 6°C and 20°C, one third of the fat globules had diameters ≤ 0.5 μm and a slightly larger proportion of them (34–38%) had diameters within the range of > 0.5 μm and ≤ 1 μm. As a result of the high-pressure homogenization of milk with initial temperatures of 40°C and 60°C, the percentages of fat globules with diameter ≤ 0.5 μm were equal to approx. 54% and 67%, respectively, and the percentage of fat globules with a diameter in the range of > 0.5 μm and ≤ 1 μm was equal to about 27%. The diameter of the majority (> 90%) of the fat globules in each of the analysed samples of homogenized milk was ≤ 2 μm (Figure 1). The microscopic images of the fat globules in the analysed milk samples are shown in Figure 2.

The results of the tests pertaining to the stability characteristics of the emulsion phase (Table 2) demonstrated that, in the case of milk processed at an initial temperature of 40°C and 60°C, the Sauter diameter of the fat globules decreased and their surface areas increased (about fivefold). The changes in the diameters of the fat globules (reduction) and their surface areas (increase) decreased with the decrease in temperature and were equal to 1.4 times in the case of milk homogenized at an initial temperature of 6°C. A similar trend related to changes depending on the initial temperature of the milk subjected to high-pressure homogenization was observed in the case of the d_v10 and d_v50 values of the fat globules. One statistically uniform group was identified, i.e., milk undergoing high-pressure homogenization at the temperatures of 40°C and 60°C. The differences between the values of the diameter and surface area of fat globules in the other milk samples subjected to homogenization were statistically significant at $\alpha = 0.05$. The characteristics of the size of the

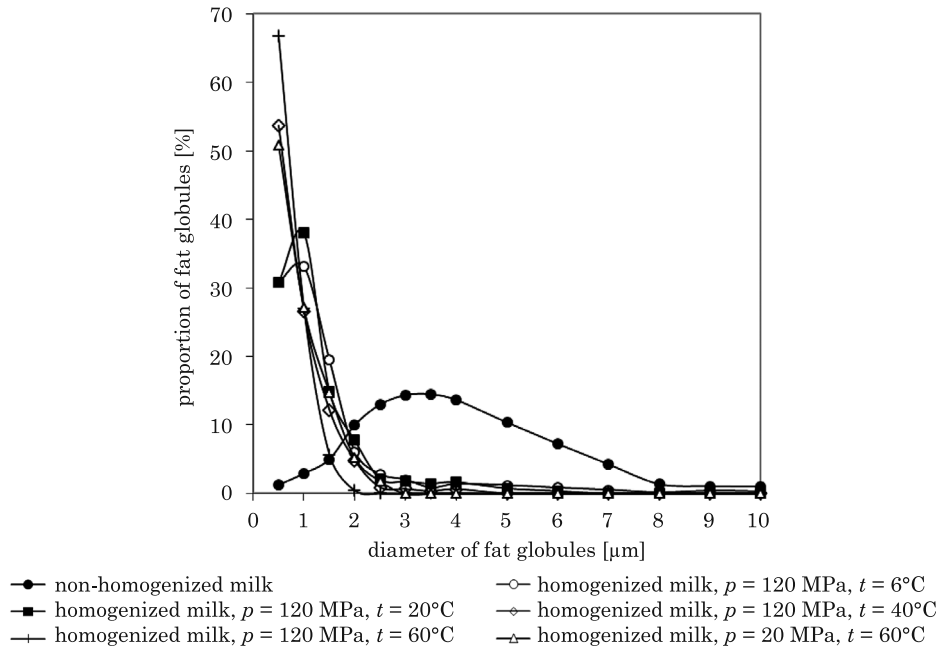

Fig. 1. Impact of homogenization on size distribution of fat globules in milk

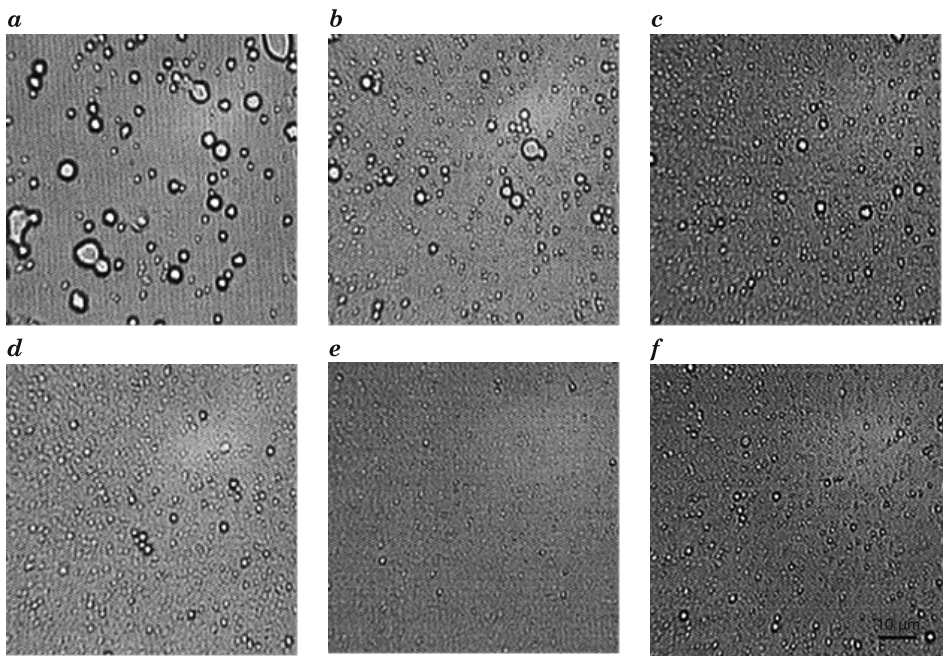

Fig. 2. Microscope images of fat globules in non-homogenized milk (*a*), milk homogenized at a pressure of 120 MPa and temperature of 6°C (*b*), 20°C (*c*), 40°C (*d*), 60°C (*e*), and milk homogenized at a pressure of 20 MPa and temperature of 60°C (*f*)

fat globules in the milk subjected to homogenization under conventional parameters corresponded to the level between sizes of the fat globules in the milk undergoing high-pressure homogenization at a temperature of 20°C and 40°C. The aforementioned trends in the changes of the analysed characteristics of milk in the homogenization process are partly confirmed in the relevant literature. The results of the research conducted by THIEBAUD et al. (2003) demonstrated an impact of homogenization conducted at a pressure of 100–250 MPa on a decrease in the diameter of fat globules with an increase in the initial temperature in the range of 4–24°C. A similar direction in the changes of the sizes of the fat globules depending on the temperature of the process was demonstrated by ZAMORA et al. (2012). They demonstrated a decrease in the Sauter diameter and an increase in the surface area of the fat globules in homogenized milk, which increased with the increase of both the pressure and the initial temperature of the milk. In their research on the impact of high-pressure homogenization at the initial milk temperature equal to approx. 7°C on the size of the fat globules, HAYES and KELLY (2003) pointed to a similar distribution of sizes obtained in milk subjected to pressure in the range of 150–200 MPa and on the impact of two-stage homogenization conducted at a pressure of 15 MPa/3 MPa and at a temperature of 50°C.

During the research, a statistically significant impact of homogenization on a reduction of the formation of a cream layer was found ($\alpha = 0.05$). Despite the reduced creaming with an increase in the temperature of the milk undergoing homogenization and the practical lack of its occurrence as a result of homogenization conducted at temperatures of 40°C and 60°C, the changes in fat content in the top and bottom layers of the milk undergoing high-pressure homogenization and conventional homogenization were statistically insignificant. When determining the volume of the cream separated during storage of milk, HAYES et al. (2005) did not observe creaming in milk that underwent high-pressure homogenization. Separation of fat during storage of homogenized milk is reduced mostly because of a decrease in the size of the fat globules, decrease of their size distribution, a reduction in the agglomeration of fat globules, decrease in the sizes of the clusters, as proven in earlier research, an increase in viscosity (KIEŁCZEWSKA et al. 2003) and adsorption of milk proteins on the surface of the fat globules (MCCRAE et al. 1994, ZAMORA et al. 2012), which increases their density (HAYES et al. 2005).

In addition to the increase of the degree of fragmentation of the fat globules, high-pressure homogenization results in a modification of the colloidal fraction of milk, which increases the sensitivity of the proteins of the homogenized milk to coagulating factors. This was statistically reflected in the significant reduction of heat stability and the reduction of the rennet coagulation time of homogenized milk, compared to the control sample (Table 3).

Table 2

Impact of homogenization on change in selected characteristics of the emulsion phase in milk

Milk			Diameter of fat globules [μm]			Surface area of fat [m^2 cm^{-3}]	Fat content [%]	
			d_{32}	d_v10	d_v50		top phase	bottom phase
Non-homogenized			2.14 ± 0.18^a	0.67 ± 0.06^a	3.76 ± 0.22^a	2.82 ± 0.23^a	9.1 ± 0.32^a	2.0 ± 0.32^a
Homogenized	t [°C]; $p_{const.}$ = 120 MPa	6	1.49 ± 0.09^b	0.52 ± 0.03^b	3.52 ± 0.21^b	4.00 ± 0.21^b	3.6 ± 0.08^b	3.4 ± 0.11^b
		20	0.92 ± 0.08^c	0.37 ± 0.03^c	1.48 ± 0.08^c	6.55 ± 0.59^c	3.5 ± 0.05^b	3.4 ± 0.13^b
		40	0.44 ± 0.03^d	0.23 ± 0.02^d	0.49 ± 0.04^d	13.56 ± 0.84^d	3.5 ± 0.02^b	3.5 ± 0.04^b
		60	0.43 ± 0.03^d	0.22 ± 0.02^d	0.47 ± 0.04^d	14.01 ± 1.05^d	3.5 ± 0.04^b	3.5 ± 0.03^b
	t = 60°C; p = 20 MPa		0.69 ± 0.05^e	0.30 ± 0.03^e	0.82 ± 0.06^e	8.77 ± 0.64^e	3.6 ± 0.05^b	3.3 ± 0.04^b

n = 6; the values in the columns marked with the same letter show no significant differences at α = 0.05

Table 3

The impact of homogenization on the colloidal stability of milk

Milk			Heat stability [min]	Rennet coagulation time [min]
Non-homogenized			11.22 ± 0.88^{a}	3.76 ± 0.09^{a}
Homogenized	t [°C]; $p_{const.}$ = 120 MPa	6	7.44 ± 0.65^{b}	2.83 ± 0.18^{b}
		20	7.93 ± 0.48^{bc}	2.98 ± 0.16^{b}
		40	8.19 ± 0.53^{bc}	3.14 ± 0.15^{b}
		60	7.99 ± 0.46^{bc}	3.36 ± 0.11^{bc}
	t = 60°C; p = 20 MPa		8.60 ± 0.53^{c}	3.41 ± 0.11^{c}

n = 6; the values in the columns marked with the same letter show no significant differences at α = 0.05

The heat stability and the rennet coagulation time of milk is reduced in most cases with the decrease of the initial temperature of the milk undergoing homogenization. The reduction in the heat stability and the rennet coagulation time as a result of high-pressure homogenization of milk with an initial temperature equal to 6°C are equal to 32% and 25%, respectively, compared to the control sample. High-pressure homogenization conducted at a temperature of 60°C results in a reduction in thermal coagulation time and rennet coagulation time of 29% and 11%, respectively. The characteristics of the resistance of homogenized milk to coagulating factors (high temperature, proteolytic enzyme) reach lower values compared to the results of homogenization at a pressure of 20 MPa and temperature of 60°C (a reduction of 23% and 9%, respectively).

The results of the research are confirmed in relevant literature, which indicate a reduction in the rennet coagulation time as a result of the high-pressure homogenization of whole milk (HAYES and KELLY 2003) and skim milk (SANDRA and DALGLEISH 2007). Also, the results of earlier research conducted by KIEŁCZEWSKA et al. (2003, 2008) demonstrated the impact of high-pressure homogenization on the reduction of rennet coagulation time and heat coagulation time of milk with different fat contents and skim milk. This is related to a change in the proportions of the components of the colloidal phase and the soluble phase as a result of the dissociation into the soluble phase of the milk of a part of the casein fractions, including the κ-casein (SANDRA and DALGLEISH 2005). The impact of high-pressure homogenization on the reduction of the quantity of the κ-casein in the colloidal form may lead to a reduction of the negative charge of the micelles, the steric repulsion resulting from the hairy surface of the micelles and the presence of a hydratation layer and the electrostatic repulsion connected with the negative charge of the micelles. These factors determine the stability of the

casein micelles. Moreover, as a result of high-pressure homogenization conducted at a temperature of 4°C and at a pressure in the range of 100–250 MPa, the casein micelles are disaggregated, which is reflected in the reduction of their sizes (ROACH and HARTE 2008). The dissociation of a part of the casein fraction into the soluble fraction of milk and disaggregation of the casein micelles may be responsible for the reduction in the resistance of proteins to the coagulating factors. In the case of whole milk, adsorption of milk proteins on the surface of fat globules, which increases as a result of homogenization, and their interactions play a significant role in the determination of stability of the proteins of homogenized milk (MCCRAE et al. 1994). The reduction of the share of the κ-casein on the surface of the fat globules, which was demonstrated using the example of recombined milk, together with the reduction of their sizes with a simultaneous increase in the level of adsorbed proteins (SHARMA and SINGH 1999), may contribute to a reduction in the heat stability of milk characterized by the presence of small fat globules. The location of casein on the surface of the fat leads to the conclusion that the behaviour of the fat globules with the adsorbed new protein material is similar to the behaviour of large casein micelles with a partially removed κ-casein, which consequently may contribute to rapid coagulation of milk (MCCRAE et al. 1994), whereby it may occur as a result of interactions between proteins present both in the milk plasma and on the surface of the fat globules. Changes in both the heat stability and the rennet coagulation time as a result of homogenization are probably due to the same changes in the components of the colloidal fraction.

Conclusions

1. High-pressure homogenization causes modification of the emulsion phase and the colloidal phase, whereby the changes depend on the temperature of the milk to be homogenized.

2. With the increase in the initial temperature of milk subjected to high-pressure homogenization, both the emulsion stability and resistance of milk to coagulating factors increase.

3. The results of the research on the selected characteristics defining stability of the emulsion phase and the colloidal phase indicate the possibility to decrease the temperature of milk undergoing high-pressure homogenization without deteriorating the results in comparison with the results of homogenization performed with conventional parameters.

4. Considering the increase of the temperature of milk, the use of the process enables homogenization of milk after initial standarisation or after

refrigerated storage for homogenization, without the preheating stage, as well as elimination of the pasteurization process while maintaining aseptic conditions.

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CONSUMER ATTITUDES AND QUALITIES DETERMINING CONSUMER SATISFACTION IN THE ORGANIC FOODS MARKET

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K e y w o r d s: organic foods, consumer attitudes, quality features.

A b s t r a c t

The objective of the studies was to investigate and determine the attitudes towards organic foods and the types and significance of the desired factors determining the satisfaction of customers who purchased organic foods products. The study was conducted as a diagnostic survey with an original questionnaire. The questions included issues on attitudes towards organic foods and the features of organic products that determined the choices of eco-consumers, frequencies and types of selected organic foods. The factors that significantly influenced the choices of organic foods were age ($p<0.05$) and place of living ($p<0.01$). The consumers of organic foods presented positive attitudes with a tendency towards neutral attitudes. The most important qualities of food that determined the satisfaction of consumers was a short shelf-life, health properties, the belief in a low content of pollutants in the organic foods and taste. The factors that were least significant for the respondents included promotional qualities.

POSTAWY I CECHY JAKOŚCIOWE WARUNKUJĄCE SATYSFAKCJĘ KONSUMENTÓW NA RYNKU ŻYWNOŚCI EKOLOGICZNEJ

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S ł o w a k l u c z o w e: żywność ekologiczna, postawy konsumenckie, cechy jakościowe.

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Abstrakt

Celem badań było określenie postaw wobec żywności ekologicznej oraz rodzaju i ważkości czynników determinujących satysfakcję nabywców ekologicznych produktów żywnościowych. Badanie przeprowadzono metodą sondażu diagnostycznego z wykorzystaniem autorskiego kwestionariusza ankiety. Badaniami objęto grupę celową liczącą 150 respondentów o zróżnicowanej płci, wieku, wykształceniu i miejscu zamieszkania. Pytania obejmowały kwestie dotyczące postaw i zachowań konsumentów wobec żywności ekologicznej. Zdecydowana większość badanych reprezentowała pozytywną postawę wobec żywności ekologicznej z tendencją do postawy neutralnej. Najbardziej oczekiwanymi cechami żywności ekologicznej w grupie regularnych jej nabywców były: krótki termin przydatności do spożycia, walory smakowe, działanie o charakterze prozdrowotnym oraz przekonanie respondentów o niższej zawartości zanieczyszczeń. Cechy o charakterze promocyjnym, tj. reklama i wygląd opakowania nie znalazły uznania wśród badanych. Do czynników, które znacząco wpłynęły na wybór żywności ekologicznej, należały wiek (p<0,05) oraz miejsce zamieszkania (p<0,01).

Introduction

In recent years, organic foods has risen in popularity in Poland and around the world (WÓJCIK 2012, *Rolnictwo ekologiczne*... 2015, *The world of organic*... 2012). It is estimated that, today, ecological agriculture is found in 162 countries. At the end of 2011, 37.2 million hectares of arable lands were of an ecological nature (WILLER et al. 2013). Since the eighties, interest in the production of organic foods increased significantly in the European Union (EU) and became one of its priorities. Within the borders of the EU, about 11 million hectares are designated for organic agriculture (WILLER et al. 2013, SMOLUK-SIKORSKA 2010). In Poland, the market of organic foods products is still in the development phase. A special interest in ecological production accompanied the access of Poland to the EU and the introduction of premiums. Polish organic agriculture has specific natural features and great development potential, which has translated into growth dynamics (MICKIEWICZ, ZUZEK 2012, ZRAŁEK 2010, NOWOGRÓDZKA 2012). In 2003–2011, the area of organic arable lands in Poland increased 10 times and today it constitutes 3.2% of the total agricultural lands (*Rolnictwo ekologiczne*... 2015). The concept of organic foods production was created due to aggressive intervention into natural ecosystems and hazards in the natural environment which resulted from the intensification of agricultural procedures, wide-spread use of plant protection chemicals as well as growth hormones and antibiotics. (LAIRON 2010). Moreover, for many consumers, the aspects of care for the natural environment, protection of natural resources and a high standard of animal welfare are also important (LAIRON 2010, MICKIEWICZ, ZUZEK 2012). The motives accompanying the consumption of organic foods may have both a rational and emotional nature. The spread and popularization of organic agriculture does not seem to be a temporary fashion, but it may express a conscious approach of the

consumer towards buying food products of the highest quality (WÓJCIK 2012). A high level of quality constitutes is one of the key categories that guarantee the safety of consumers and determines the position, attractiveness and competitiveness of a given product on the market. The concept of food production in this system also has its sceptics as well as a considerable group of enthusiasts. The objective of the studies was to investigate and determine the attitudes towards organic foods and the types and significance of the desired factors determining the satisfaction of customers who purchased organic foods.

Materials and Methods

The study was conducted as a diagnostic survey with an original questionnaire. It was composed of two parts: a general section for all respondents (n = 150) and detailed section for the respondents who declared purchasing organic foods products at least occasionally (n = 96). The selection of the examined population was intentional and included 150 persons who were visiting alternative medicine offices. The questionnaire contained exclusively multiple or single choice questions that were limited to a maximum of three answer choices. Multiple-choice questions were used only to determine the point of purchase and the assortment of organic foods products. The questions included issues on attitudes towards organic foods and the features of organic products that determined the choices of eco-consumers, frequencies and types of selected organic foods. In order to determine the attitudes of consumers towards organic foods, the quantification of the answers was performed by assigning the numerical values from 1 (Definitely, I do not agree) to 5 (I do agree) to the specific levels. Next, the numerical intervals were determined and they described the specific attitudes: negative < 1÷2.33); neutral – < 2.33÷3.67); and positive – < 3.67÷5.0>. By identifying the significance of factors determining the choice of organic foods, each answer was attributed with the point values from 1 (it is not at all important) to 5 (it is very important) and, subsequently, the arithmetical mean was calculated. The social and demographical profile of the investigated population is presented in Table 1. The statistical analysis of empirical material was conducted with a χ^2 test (p<0.05).

Results and Discussion

The consumer's satisfaction, understood as meeting his requirements, is an important factor that determines the development and achievement of a strong position for each player on the market. Due to the relatively low popularity

Table 1

Social and demographical profile of the respondents

Variable	Percentage of respondents (n = 150)	Percentage of eco-consumers (n = 96)	p*
General	100	64.0	
Sex			
Women	75.3	65.5	ns
Men	24.7	59.5	
Age (year)			
21÷30	27.3	48.8	
31÷40	30.0	77.8	**
41÷50	24.0	66.7	
51÷60	18.7	60.7	
Education			
Vocational	11.3	52.9	ns
Secondary	38.7	63.8	
University	50.0	66.7	
Place of living			
Village	15.33	73.9	
City < 100 thou.	31.33	87.2	***
City > 100 thou.	53.33	47.5	

* Significance: ** – $p \leq 0.05$; *** – $p \leq 0.01$; ns – not significant

of consumption of organic foods, the selection of the investigated group was based on a belief that the group of people visiting alternative medicine offices would be really interested in this type of food products. Of the whole investigated population, 64% of the respondents declared a frequent or occasional consumption of organic foods (Table 1).

The factors that significantly influenced the choices of organic foods were age (p<0.05) and place of living (p<0.01). Within the group of organic foods consumers, women (65.5%), persons aged 31–40 (77.8%), respondents with higher education (66.7%) and people living in the cities < 100 thousand citizens were predominant. The analysis of the results demonstrated that an inaccurate description of the "organic foods" category was one of the key issues. The organic foods requires meeting the institutionalized and legalized production methods that are a prerequisite for the certification procedure based on the national and EU regulations (MICKIEWICZ 2012, *Ustawa* z 25 czerwca 2009... Dz.U. z 2009 r., nr 116, poz. 975*, Rozporządzenie Rady...* Dz.U. nr 189, z 20 lipca 2007 r.). Although nearly all respondents (98%) declared knowing this food category. Within this group, 63.5% of persons pointed to the requirement for certification of organic production procedures. The other respondents did not think of the need for certification and pointed to the non-certified food from farms or self-produced food. ZRAŁEK (2010) has also indicated a compar-

Table 2

The average values describing the attitudes of respondents towards organic foods

Variable	The average values for statements										$\bar{x}$
	Statement*										
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	
General	4.41	4.33	3.99	3.92	3.93	3.90	3.88	3.16^{n}	2.98^{n}	3.51^{n}	3.80
Sex											
Women	4.44	4.35	3.95	3.90	3.90	3.94	3.88	3.29^{n}	3.04^{n}	3.59^{n}	3.83
Men	4.30	4.27	4.11	3.97	4.00	3.78	3.89	2.76^{n}	2.81^{n}	3.24^{n}	3.71
Age (year)											
21÷30	4.37	4.32	3.83	3.61	3.76	3.63^{n}	3.76	3.05^{n}	3.27^{n}	3.56^{n}	3.72
31÷40	4.60	4.62	4.04	4.22	3.87	4.02	3.87	2.84^{n}	2.76^{n}	3.24^{n}	3.81
41÷50	4.25	4.31	3.97	3.89	4.06	4.08	3.72	3.89	3.53^{n}	3.53^{n}	3.92
51÷60	4.36	3.93	4.14	3.93	4.11	3.86	4.29	2.89^{n}	**2.21**	3.82^{n}	3.75
Education											
Vocational	4.35	4.29	4.06	3.71	4.47	3.76	3.94	3.06^{n}	2.53^{n}	3.76	3.79
Secondary	4.17	4.21	3.67	3.91	3.90	3.88	3.76	3.34^{n}	2.67^{n}	3.57^{n}	3.71
University	4.60	4.44	4.23	3.97	3.83	3.95	3.96	3.04^{n}	3.32^{n}	3.40^{n}	3.87
Place of living											
Village	4.30	4.48	3.83	4.17	3.87	3.96	3.57	3.09^{n}	**2.17**	3.70	3.71
City < 100 thou.	4.45	4.42	4.09	4.15	4.11	3.96	3.83	2.96^{n}	2.81^{n}	3.87	3.87
City > 100 thou.	4.41	4.24	3.98	3.71	3.85	3.85	4.00	3.30^{n}	3.31^{n}	3.24^{n}	3.79

Explanations: attitude regular type – positive; superscript ^{n} – neutral; bold type – negative
* *1* – I have a positive attitude towards organic foods; *2* – There are considerable benefits from introducing organic foods to the diet; *3* – There is a high risk to health associated with its consumption; *4* – In the future, I will continue to consume organic foods; *5* – Organic foods has worse taste, smell and look; *6* – Organic foods is of higher quality than traditional food; *7* – Organic foods is trendy; *8* – Organic foods is less durable; *9* – Organic foods is healthier than traditional food; *10* – Organic foods is the food of the future.

able problem of inaccurate perception and definition of organic foods by consumers. The results may indicate that the level of education of consumers in these subject areas is relatively low which, in turn. The lack of knowledge and erroneous beliefs may translate into specific attitudes and behaviours of consumers in relation to a given product. The lack of knowledge of the respondents may be explained by a still minor popularity of the products from this food segment in Poland. Some other reports have also indicated an issue of the lack of knowledge of organic foods and conditions of ecological production and a specific information gap (ŻAKOWSKA-BIEMANS 2011a, WITEK 2011).

The consumer's attitude towards an organic foods, is one of the factors that may be very important in determining the consumer's behaviours. However, it should be considered that the relation between the attitude and behaviour may not be straightforward. Although a positive or negative attitude does not necessarily translate into specific behaviours, it may be predisposing. The incongruity between consumer attitudes and behaviours has been widely

discussed (JEŻEWSKA-ZYCHOWICZ, PILSKA 2007). Table 2 shows the average numerical values describing the attitudes of respondents towards organic foods. The presented study demonstrated that the examined population of respondents had a positive attitude towards organic foods. Considering the average value for a specific division criterion for the investigated group and all 10 statements, the obtained values were within the range of 3.71 and 3.92. Distribution of these values corresponded to positive attitudes with a tendency towards neutral attitudes. The differences in the average values as a function of the assumed division criterion for the examined population were minor and statistically insignificant. Such small diversification of the declared attitudes may be explained by the relative homogeneity of the beliefs within the examined population determined by a specific attitude towards a healthy lifestyle. A positive attitude to organic foods was shown mainly by women ($\bar{x}$ = 3.83), persons aged 41÷50 ($\bar{x}$ = 3.92), persons with higher education ($\bar{x}$ = 3.87) and residents of the cities with less 100 thousand inhabitants ($\bar{x}$ = 3.87).

A thorough analysis of the attitudes that included the individual statements demonstrated that the respondents generally had positive attitudes (statements 1–7) for which $\bar{x}$ ranged from 3.88 to 4.41 and neutral attitudes (statements 8–9) for which $\bar{x}$ = 2.98÷3.51. The proportion of negative attitudes was marginal and related only to statement 9 (assessment of health qualities in organic foods). This attitude was represented by persons from the oldest age group and the inhabitants of rural areas. Apart from these two groups, the values describing the attitudes of other respondents towards the same statement were, also low. It is difficult to explain this distribution of values since, in the common opinion of the respondents, that the organic foods is of high quality and is associated with healthy food. Furthermore, care for health is one of the most important motives behind buying organic foods by Poles (ZRAŁEK 2010, ŻAKOWSKA-BIEMANS 2011b, CICHOCKA, GRABIŃSKA 2009). Presented distributions of the values characterizing the attitudes of the respondents do not correspond to their declarations related to the importance of the factors determining the choices of organic foods.

Analysis of the data on the consumption of organic foods products by a Polish consumer, showed that it is minor. Despite the observed development of the organic foods market, considered that eco-consumption is still perceived as a niche item. The demonstrated positive attitude of the respondents towards organic foods was reflected in nutritional behaviours. The examined population was characterized by a relatively high frequency of consumption of the products from this group (Table 3).

Table 3

Frequency of consumption of organic foods

Variable	Frequency					p*
	daily	4÷6 times per week	1÷3 times per week	few times per month	less	
	percentage of organic consumers					
General	9.4	7.3	31.3	41.6	10.4	
Sex						
Women	10.8	35.1	32.4	9.5	12.2	ns
Men	0	0	27.3	63.6	9.1	
Age (year)						
21÷30	10.0	5.0	30.0	45.0	10.0	
31÷40	5.7	0	40.0	45.7	8.6	**
41÷50	8.3	4.2	33.3	37.5	16.7	
51÷60	17.6	29.4	11.8	35.3	5.9	
Education						
Vocational	0	0	44.4	22.2	33.4	
Secondary	13.5	16.2	21.6	40.5	8.2	**
University	8.0	2.0	36.0	46.0	8.0	
Place of living						
Village	18.8	0	31.2	43.7	6.3	
City < 100 thou.	12.2	9.8	24.4	43.8	9.8	ns
City > 100 thou.	2.6	7.9	39.5	36.8	13.2	

* Significance: ** – $p \leq 0.05$; ns – not significant

The highest number of respondents (41.7%) declared consuming organic foods a few times per month. The men were predominant in this group (63.6%) while the women constituted 9.5%. Approximately 31% of the respondents consumed organic foods from 1 to 3 times per week (32.4% of women and 27.3% of men). The consumers that ate organic products on a daily basis constituted 9.4%, while 7.3% of the examined population consumed these products 4 to 5 times per week. In both cases, these were women who constituted 10.8% and 35.1%, respectively, of the investigated female population. According to criterion of age, it was found that it had a significant impact ($p<0.05$) on the frequency of organic foods consumption. Despite the differences, the respondents of each age range consumed products from this food category mainly a few times per month. The highest frequency of consumption was recorded among the oldest consumers followed by the youngest respondents. The level of education also impacted significantly ($p<0.05$) the frequency of organic foods consumption. Respondents with vocational secondary education consumed organic foods the least rarely while those with secondary education did so the most frequently. The frequency of consumption was relatively low in the group of respondents with university education. The distribution of the results did not provide a complete confirmation of the data, indicating a high interest in

the organic foods characteristics in the group of young and well-educated consumers (WITEK 2011). It may be explained by the power of motivation in the older consumers who, in the face of health complaints, decided to turn towards a healthy lifestyle. The place of living did not influence any significant impact on the frequency of organic foods consumption. A large proportion of organic foods in the daily diet of village residents resulted from a higher availability of this food category and a wrong understanding of the "organic foods" category. Self-produced and uncertified food was also perceived as organic foods. The residents of towns with less than 100 thousand inhabitants more frequently included organic products in their diet in comparison with the group of inhabitants of bigger cities. This does not confirm the assumption that the strongest pro-ecological attitudes are shown by the residents of large urban agglomerations (ZRAŁEK 2010).

Access to a wide range of organic foods products may present a real problem for the Polish consumer. The most common bottleneck of the Polish organic foods market is its low availability which mainly results from a limited number of production sites and selling points. Moreover, the problem lies in a poorly developed and inefficiently organized channel network and infrastructural back support (ŻAKOWSKA-BIEMANS 2011ab, ZUBA 2001). The presented studies show that, for the majority of the respondents, the main place where organic foods was purchased are specialized shops (64%) and supermarkets (49%). Only in the group of rural inhabitants, was organic foods bought directly from its producers (55%). Internet-based shops were indicated by only 4 persons. The studies by STEFAŃSKA (2010) have demonstrated that 40% of consumers buy organic foods in specialized shops and the same percentage in supermarkets and 12% – on markets. The rest consumers buying directly on eco-farms and agritourist farms. Specialist shops are thought to have the highest efficiency of eco-product distribution. This mainly results from their trade offer and knowledge of their staff (ZUBA 2001, ŻAKOWSKA-BIEMANS 2008). An increase in the share of supermarkets in the global selling of organic foods is seen as a potential direction of changes, leading to the creation of supermarkets that would exclusively offer eco-products (WITEK 2011, ŻAKOWSKA-BIEMANS 2008). It is becoming more common that organic foods can be purchased via the Internet (ŁUKASIŃSKI 2008).

Among the most frequently bought products, the following were predominant: eggs (61.5%), fruit and vegetables (55.2%), bakery products (31.3%), herbs (25.0%), and cereal products (24.0%). Milk, meat and meat products as well as fermented products were less popular (< 20%).

In the age of the market-driven economy, quality has become the basic category that determines the degree of product competitiveness. The perception of organic foods quality parameters by its consumers mainly focuses on

Table 4
The significance of the organic food features desired by the consumer in relation to sex, age, education and place of living

Variable	The average values for quality features												
	quality features of organic foods												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
General	4.51	4.32	4.30	4.28	3.99	3.94	3.82	3.81	3.64	3.56	2.93	2.46	2.43
Sex													
Women	4.64	4.27	4.27	4.34	3.99	4.09	3.78	3.81	3.73	3.58	2.95	2.47	2.58
Men	4.09	4.32	4.41	4.27	4.0	3.41	3.95	3.82	3.32	3.50	2.86	2.41	1.91
p	**	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	*
Age (year)													
21÷30	4.25	4.05	4.15	4.20	3.95	3.70	4.0	3.5	3.70	2.95	2.65	2.45	1.80
31÷40	4.51	4.74	4.46	4.71	4.26	3.66	3.60	4.0	3.80	3.71	3.09	2.34	2.49
41÷50	4.83	3.88	4.33	4.13	3.83	4.29	3.63	3.92	2.92	3.71	2.67	2.58	2.50
51÷60	4.35	4.18	4.12	3.94	3.71	4.29	4.35	3.65	4.24	3.76	3.29	2.53	2.94
p	*	**	ns	**	ns	ns	ns	ns	*	ns	*	ns	**
Education													
Vocational	4.78	3.11	4.67	3.78	4.0	3.89	4.33	4.0	3.67	4.0	3.33	2.56	2.78
Secondary	4.46	4.32	4.22	4.08	3.92	4.3	3.78	3.89	3.54	3.65	3.03	2.81	2.81
University	4.5	4.46	4.30	4.60	4.04	3.68	3.76	3.72	3.70	3.42	2.78	2.18	2.08
p	Ns	**	ns	**	ns	**	ns	ns	ns	ns	ns	*	**
Place of living													
Village	4.88	4.24	4.65	4.18	4.47	4.18	3.82	4.35	3.82	4.29	2.94	3.18	2.76
City < 100 thou.	4.51	4.51	4.22	4.44	3.63	3.80	3.93	3.56	3.73	3.54	2.85	2.15	2.39
City > 100 thou.	4.34	4.05	4.24	4.26	4.16	3.97	3.71	3.84	3.45	3.26	3.0	2.47	2.32
p	**	ns	*	**	*	ns	ns	**	ns	**	ns	*	ns

1 – short shelf-life; *2* – health properties; *3* – belief in a lower level of pollutants; *4* – taste; *5* – product composition; *6* – product origin; *7* – price; *8* – ecological method of production; *9* – certification; *10* – belief in the superiority of ecological products over traditional food; *11* – appearance of a product; *12* – promotional actions and advertising; *13* – appealing package
Significance: * – $p \leq 0.05$; ** – $p \leq 0.01$; ns – not significant

the group of products that are certified and compliant with specifications. Among the most frequently expected qualities of organic foods, the following are listed: health properties, taste, safety determined by a lower level of pollutants and shelf-life (ZRAŁEK 2010, ŁUKASIŃSKI 2008, CICHOCKA, GRABIŃSKI 2009). Consumers believe that promotional factors such as advertising, an appealing package, price and brand play a considerable role in creating the image of a product and, consequently, contribute to the customer's satisfaction. ZRAŁEK (2010) demonstrated that the selection of organic foods by the Poles is determined by numerous factors and the strength of each is evaluated differently. Moreover, depending on the changes to the economic, social or environmental surroundings, some individualized fluctuations of the expectation catalogue may occur.

The current studies analysed the significance of the selected factors that mainly contribute to the positive perception of organic foods and determine the choices of this group of products. Based on the collected material it was found that the most desired descriptors of organic foods in the group of real and occasional buyers were: short shelf-life ($\bar{x}$ = 4.51), health properties ($\bar{x}$ = 4.32) and the belief in a lower level of pollutants ($\bar{x}$ = 4.30) and taste ($\bar{x}$ = 4.28). The least important factors, according to the respondents, were: general appearance of a product ($\bar{x}$ = 2.93), promotional actions and advertising ($\bar{x}$ = 2.46) and an appealing package ($\bar{x}$ = 4.30) – Table 4. A relatively short shelf-life was perceived by the consumers as a lack of preservatives. Shelf-life may also be used as a criterion for differentiation between organic and non-organic foods (ZRAŁEK 2010). Health qualities were the second factor. In the majority of publications these properties are one of the most important factors characterizing this group of products and are one of the key motives that drive eco-consumers (ZRAŁEK 2010, CICHOCKA, GRABIŃSKI 2009).

The current study found a lack of correlation between the strength of the selected determinant, i.e. health qualities of ogganic foods, and the declared attitude (neutral and negative) towards its health attributes. The next factor to which the respondents paid special attention was a common belief in a lower level of pollutants and harmful substances in organic foods. This factor is responsible for the safety of food and constitutes a key component of its quality. Similar to health properties, the safety of organic foods is one of the most frequently selected features which drives the choices of organic foods products made by consumers. The importance of this aspect is unquestionable and has been widely discussed (ZUBA 2001, GERTIG 2010). Taste was another important determinant. In the case of taste qualities, the subjectivity of an assessment must be assumed depending on the individual sensory sensitivity of a consumer. In addition, it is thought that a given method of organic foods production may not influence its taste or it may be very individualized and ambiguous (ZRAŁEK 2010). Price was another important factor. In the investigated group of respondents, the price was not enumerated as the most important factor driving the choice of organic foods ($\bar{x}$ 3.82). It is thus supposed that some of the respondents are willing to pay higher prices for such products. The level of organic foods pricing is always higher than the prices of products manufactured with conventional methods. These differences are usually around 20–30% (NOWOGRÓDZKA 2012) and result from higher production costs, poorly-developed organic foods processing, high distribution costs, a large share of imported products on the market and a level of profit margins. For many eco-consumers (app. 50%), the high pricing of organic foods constitutes a real barrier to purchasing. There is, however, a group of consumers who are willing to pay higher prices for organic foods. Within this group, a belief in the

higher quality of purchased organic products creates a situation in which price is not a major factor (NOWOGRÓDZKA 2012, ŻAKOWSKA-BIEMANS 2011a, CICHOCKA, GRABIŃSKI 2009). This attitude depends on the level of income of a potential consumer. In Poland, a willingness to pay a higher price for an organic foods, in comparison with a conventional product, is declared by over a half of the respondents, although the majority of them accept a price increase of up to 10%. Both in Poland and around the world, the acceptance threshold for a price increase ranges from 10 to 20% (WITEK 2011).

The inaccurate definition of "organic foods" was reflected in the attitude of the respondents towards organic foods certificates. Although it is obligatory for organic foods to have certificates, it does not necessarily translate into the consumer's trust in the ecological origin of food (ŻAKOWSKA-BIEMANS 2011a). It is supposed that minor significance of the certificate ($\bar{x} = 3.64$) for consumers could result from a wrong perception of organic foods or a lack of trust in the certified organic foods. The promotional features, i.e. advertising and an appealing package, were not acknowledged by the respondents ($\bar{x} = 2.46$ and $\bar{x} = 2.43$, respectively). In the examined group of respondents, an appealing nature of food packages was not a desired parameter. It may result from a potential conflict between the ecological motivation and aesthetical motives of the consumer. For the investigated group, the content of the package was more important than its attractiveness. In the context of this data, it is worth mentioning that there are some marketing actions that consist in introducing simple and plain packages that should affect the emotional needs of the eco-consumer. Table 4 presents the significance of the organic food features desired by the consumer in relation to sex, age, education and place of living. It demonstrates that, in the majority of cases, the statements made by the women and the men did not differ and, therefore, most of the factors had a similar importance for both sexes. The statistical differences were only shown for the following factors: short shelf-life ($p<0.01$), product origin ($p<0.01$) and package attractiveness ($p<0.05$). The women paid more attention to these factors. According to criterion of age, it was found that it had a significant impact ($p<0.01$) on the following factors: health properties, taste, appealing package and ($p<0.05$) short shelf-life, certification and appearance of a product. The level of education influenced the differences in the perception of significance of the desired organic foods qualities. Significant statistical differences ($p\leq0.01$) were recorded for health properties, taste, product origin, appealing package appearance and ($p\leq0.05$) were recorded for promotional actions and advertising. In the majority of cases, the place of living significantly influenced the differences in the perception of significance of the desired organic foods qualities.

Conclusions

The consumers of organic foods presented positive attitudes with a tendency towards neutral attitudes. The positive attitudes translated into the frequency of organic foods consumption. The highest number of respondents declared consuming organic foods a few times per month. The main purchase locations were, respectively: specialized shops, supermarkets and discount shops and organic foods producers. The most important characteristics and qualities of food that, to the highest degree, determined the satisfaction of consumers was a relatively short shelf-life, health properties, the belief in a low content of pollutants in the food manufactured with ecological methods and taste qualities. These parameters indicate the special significance of the attributes which determine the safety of the customer and meeting his/her desired taste sensations. The second and less important group of factors included the composition and origin of a product, price, organic production methods, certification and a belief in the superiority of organic foods over the products manufactured with traditional methods. The factors that were least significant for the respondents included promotional qualities, such as the appearance of a product, promotional campaigns and advertising and having an appealing package.

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EFFECT OF FREEZING AND ENZYMATIC TREATMENT ON THE OUTPUT OF JUICE AND EXTRACTION OF PHENOLIC COMPOUNDS IN THE PRESSING OF LINGONBERRY FRUIT

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K e y w o r d s: lingonberry, total phenolic, anthocyanins, juice.

A b s t r a c t

This paper presents the therapeutic properties of lingonberry and discusses all of the groups of phenolic compounds and anthocyanins. It describes the effect of selected technological operations: freezing and enzymatic maceration of pulp on the content of phenolic compounds in the fruit and juice obtained from them. The antioxidative activity of phenolic compounds present in fruit and juice was also determined.

The study has shown that productivity of pressing juice from pulp obtained from frozen fruit following enzymatic treatment was higher than for pressing the pulp from cold-stored fruit.

The content of phenolic compounds in the juice obtained from lingonberry fruit decreased compared to the fruit. The amount of phenolic compounds which remained in the pulp after pressing ranged from 16.9% to 25.4%, and that of anthocyanins – from 37.2% to 46.1%. The highest content of phenolic compounds was found in juice obtained from the pulp of frozen fruit. All of the juices under study showed high antioxidative activity.

WPŁYW MROŻENIA I OBRÓBKI ENZYMATYCZNEJ NA WYDAJNOŚĆ SOKU I WYDOBYCIE ZWIĄZKÓW FENOLOWYCH PODCZAS TŁOCZENIA OWOCÓW BORÓWKI BRUSZNICY

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S ł o w a k l u c z o w e: borówka brusznica, związki fenolowe, antocyjany.

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Abstrakt

W pracy przedstawiono właściwości lecznicze borówki brusznicy oraz omówiono wszystkie grupy związków fenolowych i antocyjanów. Opisano wpływ wybranych zabiegów technologicznych: mrożenia i enzymatycznej maceracji miazgi na zawartość związków fenolowych w owocach i sokach z nich otrzymanych. Określono aktywność przeciwutleniającą związków fenolowych występujących w owocach i sokach.

Na podstawie przeprowadzonych badań stwierdzono, iż wydajność tłoczenia soku z miazgi otrzymanej z owoców mrożonych i po obróbce enzymatycznej była wyższa niż w przypadku tłoczenia miazgi otrzymanej z owoców przechowywanych w chłodni.

W otrzymanych z borówki brusznicy sokach nastąpiło zmniejszenie zawartości związków fenolowych w porównaniu do ich ilości w owocach. Ilość związków fenolowych pozostająca w miazdze po tłoczeniu wynosiła 16,9–25,4%, a antocyjanów 37,2–46,1%. Najwyższa zawartość związków fenolowych występowała w soku uzyskanym z miazgi owoców mrożonych. Wszystkie badane soki wykazywały wysoką aktywność przeciwutleniającą.

Introduction

In recent years, the tradition of obtaining juice from forest fruit, such as bilberry (*Vaccinium myrtillus* L.), lingonberry (*Vaccinium vitis-idaea* L.) and cranberry (*Vaccinium oxycoccus* L.) has been returning. Forest fruits are processed by small fruit processing facilities. Raw fruits obtained in the process are usually a component of multi-fruit juices, known as one-day juices or low-pasteurisation juice. Their presence in the recipe enriches the final product in valuable bioactive substances. Obtaining raw juice rich in bioactive substances is difficult because most of these substances, mainly phenolic compounds, are found in the skin cells or in cells directly underneath it. These cells are surrounded by much thicker cell walls which are much more difficult to break than fruit pulp cells. Therefore, the process of fruit pressing is frequently preceded by mechanical or enzymatic pre-treatment. These processes allow juice to be obtained with an increased content of bioactive substances.

The aim of the study was to establish to what extent freezing fruit followed by defrosting and enzymatic treatment of the pulp affect the output and quality of the juice. The study was conducted with a view to obtaining juice with improved therapeutic properties.

The study was conducted to determine the pressing productivity, the amount of dry matter and extract and the content of selected groups of polyphenols in the juices.

Materials and Methods

Lingonberry fruit picked in forests in the north of Poland (near Łeba) were used as the study material. A batch of fruit of 5 kg was divided into two parts. One part was stored under refrigerated conditions at 6–8°C and the other was frozen and stored at -18°C. Both batches were vacuum-packed in plastic packaging. After storing the fruit for a month, juice was obtained from them. The organisation of the experiment involved production of juice in three options:

Juice was obtained from frozen fruit in the following manner: 2 kg of frozen fruit were defrosted and ground in a food processor (Thermomix TM 31 Varoma Vorwerk) and the pulp was pressed in a laboratory press (Profil Press, Germany) at the pressure of 250 bar, thus yielding raw juice. The juice was filtered through a laboratory filter (Filter 20x20 · 14K STL pump RVR).

Juice from cold-stored fruit was obtained in the following manner: 3 kg of fruit was ground in a food processor. The pulp was divided into two parts. One part was pressed on a laboratory press and the obtained juice served as the control juice. The other part was treated enzymatically (maceration).

An enzymatic preparation (Pectinex BE XXL by Novozymes) was used; before being applied it was diluted 10 times with distilled water.

Maceration of 1.5 kg of the pulp was carried out with 0.35 ml of 10% of the enzyme solution; the whole solution was mixed thoroughly and incubated at 50°C for 2 hours. After the incubation, the pulp was pressed on a laboratory press (250 bar). The juice was filtered through a plate filter. The characteristics of the enzymatic preparation Pectinex BE XXL manufactured by Novozymes were: activity 30000 UPTE · ml^{-1}; main and secondary activity: pectin lyase; optimum pH: 3.0–5.0; optimum temperature: 50–60°C (recommendations from Novozymes).

Methods

The following were determined in the fruit and in juices: dry matter by weighing according to PN-90:A-75101:03, total phenolic compounds as equivalent of gallic acid according to AOAC, (1974) and SHAHIDI and NACZK (1995), anthocyanins as cyanidin-3-glycoside according to Wrolstad (AOAC 1974), DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity μM $DPPH^{\cdot}$ by 1 mg of phenolic compounds according to BRAND-WILLIAMSI et. al. (1995), MOURE et. al. (2001). For easier comparison of the results in this experiment with the results cited in the literature, the results were given per unit mass of juice and fruit on the dry weight basis.

Statistical analysis

Obtained results of researches were statistically analyzed using the Statistica 10.0 PL (StatSoft, Kraków, Poland) program, (ANOVA) with Duncana test of $p \leq 0.05$ significance level was used.

Discussion of Results

The study found that cold-stored lingonberry fruit contained 82.70 ± 5.89% of cell juice with 13.83 ± 0.15% extract. A similar content of juice (82.10 ± 6.50%) and extract (13.35 ± 0.22%) was found in frozen fruit (Table 1). Similarly slight differences were found in the content of individual groups of phenolic compounds (Table 2).

Table 1

The water conten and the extract content in fruit lingonberry

Fruits	Water content [%]	Extract content [%]
Stored in refrigeration	82.70 ± 5.89^a	13.83 ± 0.15^a
Frozen	82.10 ± 6.50^a	13.35 ± 0.22^b

Table 2

The total amountof phenolic compounds, anthocyanins in fruit lingonberry stored in refrigeration, and frozen

Fruits	Total phenolic compounds		Anthocyanins	
	fresh matter mg 100 g^{-1}	dry matter mg 100 g^{-1}	fresh matter mg 100 g^{-1}	dry matter mg 100 g^{-1}
Stored in refrigeration	698.55 ± 42.20^a	4037.86 ± 320.00^a	95.30 ± 5.35^a	550.86 ± 18.15^a
Frozen	705.10 ± 52.60^a	3939.10 ± 88.00^a	89.69 ± 7.60^a	501.06 ± 30.02^a

a, b – mean values indicated by the same letter do not differ significantly ($p \leq 0.05$)

It was established that the total content of phenolic compounds in cold-stored lingonberry fruit was 698.55 ± 42.20 mg · 100 g^{-1} of fruit (4037.86 ± 320.00 mg · 100 g^{-1} d.m.), and in frozen fruit – 705.10 ± ± 52.60 mg · 100 g^{-1} of fruit (3939.10 ± 88.00 mg · 100 g^{-1} d.m.). Similarly, a small difference was observed for anthocyanins, whose content in cold-stored fruit was 95.30 ± 5.35 mg · 100 g^{-1} of fruit (550.86 ± ± 18.15 mg · 100 g^{-1} d.m.), and in frozen fruit – 89.69 ± 7.60 mg · 100 g^{-1} of fruit (501.06 ± 30.02 mg · 100 g^{-1}) (Table 2).

Pressing cold-stored fruit yielded 71.0 ± 2.5% of juice containing 13.65 ± 0.95% of dry matter and 10.85 ± 0.15% of extract. The content of phenolic compounds was 489.23 ± 40.83 mg · 100 g^{-1} of juice (3584.10 ± ± 383.32 mg · 100 g^{-1} d.m.) and anthocyanin contents were 65.70 ± ± 3.22 mg · 100 g^{-1} of juice (481.32 ± 30.24 mg · 100 g^{-1} d.m.) – Table 3.

Table 3

The amount of dry matter and extract the juice obtained from the lingonberry

Product	Yield [%]	Dry matter [%]	Extract content [%]
The juice from the pulp of the fruit stored in refrigeration	71.0 ± 2.5^a	13.65 ± 0.95^a	10.85 ± 0.15^a
The juice from the pulp of the fruit frozen	75.2 ± 0.9^b	15.44 ± 1.50^a	10.99 ± 0.10^a
The juice from the pulp after enzymatic maceration	77.1 ± 1.9^b	14.86 ± 1.00^a	9.83 ± 0.15^b

a, b – mean values indicated by the same letter do not differ significantly ($p \leq 0.05$)

The data gathered in these assays showed that 50% of the total amount of phenolic compounds and 49% of the anthocyanins present in the fruit were extracted by pressing the cold-stored fruit (Figure 1).

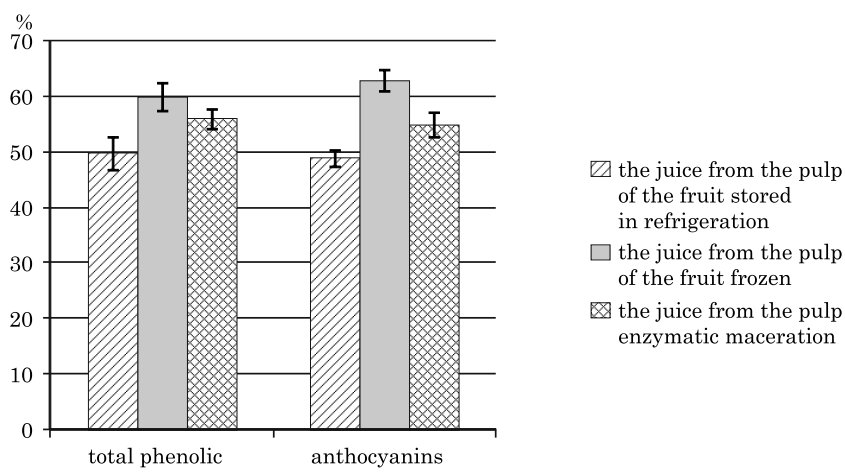

Fig. 1. The percent extraction of total phenolic compounds and anthocyanins to juice

Pressing the fruit pulp from frozen fruit yielded 75.2 ± 0.9% of juice. The juice contains 15.44 ± 1.50% of dry matter and 10.99 ± 0.10% of extract (Table 3). The juice contained the largest amounts of total phenolic compounds of 559.89 ± 44.98 mg · 100 g^{-1} of juice (3625.23 ±

± 393.19 mg · 100 g^{-1} d.m.) and 74.48 ± 2.74 mg anthocyanins in 100 g of juice (482.38 ± 23.98 mg · 100 g^{-1} d.m.) – Table 4. Pressing frozen fruit resulted in the extraction of approx. 60% of polyphenols and approx. 63% of anthocyanins present in the fruit (Figure 1). It was established by applying different methods of fruit preparation for pressing that the highest yield (77.1 ± 1.9%) was achieved by pressing pulp following its enzymatic maceration. The juice contained 14.86 ± 1.00% of dry matter and 9.83 ± 0.15% of extract (Table 3). The content of phenolic compounds was 502.58 ± 40.38 mg in 100 g of juice (3382.10 ± 371.91 mg · 100 g^{-1} d.m.), and that of anthocyanins 68.54 ± 1.13 mg in 100 g of juice (461.24 ± ± 10.43 mg · 100 g^{-1} d.m.). Owing to enzymatic pre-treatment, approx. 56% of phenolic and 55% of anthocyanins were extracted in the juice (Figure 1).

Table 4

The total amount of phenolic compounds, anthocyanins in juices

Product	Total phenolic compounds converted on gallic acid		Anthocyanins converted into content as cyanidin-3-glycoside	
	fresh matter mg 100 g^{-1}	dry matter mg 100 g^{-1}	fresh matter mg 100 g^{-1}	dry matter mg 100 g^{-1}
The juice from the pulp of the fruit stored in refrigeration	489.23 ± 40.83^{a}	3584.10 ± 383.32^{a}	65.70 ± 3.22^{a}	481.32 ± 30.24^{a}
The juice from the pulp of the fruit frozen	559.89 ± 44.98^{b}	3625.23 ± 393.19^{b}	74.48 ± 2.74^{b}	482.38 ± 23.98^{b}
The juice from the pulp enzymatic maceration	502.58 ± 40.38^{b}	3382.10 ± 371.91^{ab}	68.54 ± 1.13^{a}	461.24 ± 10.43^{ab}

a, b – mean values indicated by the same letter do not differ significantly ($p \leq 0.05$)

The higher productivity of fruit pressing was consistent with the findings of other studies, whose authors showed that enzymatic maceration of pulp increased the productivity of pressing and effectiveness of compounds to juice (SZAJDEK et al. 2006, OSZMIAŃSKI 2007a, OSZMIAŃSKI 2007b, KALISZ 2008, NADULSKI and WAWRYNIUK 2009).

All of the juices contained less phenolic compounds and anthocyanins compared to the lingonberry fruit stored under refrigerated conditions, from which they were obtained. This was probably caused by insufficient release of the compound from a hard skin in which their content is the highest (OSZMIAŃSKI 2007a, OSZMIAŃSKI 2007b, KALISZ 2008, NADULSKI, ZAWIŚLAK 2013).

The highest antioxidative activity was manifested by juice obtained from cold-stored fruit (6.63 ± 0.64 μM $DPPH^{\cdot}$ was scavenged by 1 mg of phenolic compounds), which was 19.16% more than the activity of the raw material.

Lower antioxidative activity was observed in the juice obtained from pulp after enzymatic maceration (6.09 ± 0.54 μM $DPPH^{\cdot}$ was scavenged by 1 mg of phenolic compounds, which was 8.1% lower than for the juice obtained from cold-stored fruit (control) and the lowest was the juice from pulp obtained from frozen juice – 5.94 ± 0.12 μM $DPPH^{\cdot}$ scavenged by 1 mg of phenolic compounds (10.4% lower than the control juice) – Table 5.

Table 5

The antioxidant activity of phenolic compounds present in the studied juice

	The juice from the pulp of the fruits stored in refrigeration	The juice from the pulp of frozen fruit	The juice from the pulp after enzymatic maceration
	μM $DPPH^{\cdot}$ scavenged by 1 mg of phenolic compounds		
Juice	6.63 ± 0.64	5.94 ± 0.52	6.09 ± 0.54

Conclusions

The productivity of pressing juice from pulp obtained from frozen fruit following enzymatic treatment was higher than for pressing the pulp from cold-stored fruit. The lower productivity may be caused by the fact that cell walls in fresh or cold-stored fruit remain elastic and difficult to crush mechanically. This has been reported in many publications which describe the pre-treatment of the raw material (ZADERNOWSKI and OSZMIAŃSKI 1994). The low extent to which cells were broken resulted in a low content of phenolic compounds, especially anthocyanins, in the juices compared with the content in cold-stored fruit. In effect, the remainder after pressing cold-stored fruit contained approx. 50% phenolic compounds and 51% anthocyanins, the remainder after pressing frozen fruit contained 40% phenolic compounds and approx. 38% anthocyanins and the remainder after pressing pulp following enzymatic pre-treatment contained 44% of the total phenolic compounds and approx. 45% of anthocyanins. These differences indicate the great diversity of the degradation extent of the cellular walls. The highest antioxidative activity was observed in the juice obtained from cold-stored fruit following treatment.

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COMMODITY ANALYSIS OF QUALITY CHANGES IN FROZEN STRAWBERRY CAUSED BY TEMPERATURE FLUCTUATIONS

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K e y w o r d s: strawberry, frozen fruits, temperature fluctuation, quality changes.

A b s t r a c t

The objective of the studies was to evaluate the level of quality changes in frozen strawberry stored at fluctuating temperatures and to verify H_0: the levels of the tested parameters within time occurred as the arithmetic mean of the levels of these traits recorded under extreme conditions. The studies were carried out with frozen strawberries stored at constant temperatures of –18°C and –25°C and at variable temperatures of –18°C/–25°C in a 48-hour exchange cycle. The fruits were tested for the content of anthocyans and vitamin C, total and active acidity, and thawing spill before storage and at 4-week cycles for the total of 24-week storing period. Although verification of H_0 demonstrated that the values of the examined traits were not equal to the levels recorded under extreme conditions, they were slightly divergent from the assumed hypothetical values. For the majority of the analysed parameters, the temperature fluctuations caused a slightly lower degree of changes than it would appear from the arithmetic mean at extreme temperatures.

TOWAROZNAWCZA OCENA ZMIAN JAKOŚCI MROŻONYCH TRUSKAWEK WYWOŁANYCH FLUKTUACJĄ TEMPERATURY

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Abstrakt

Celem badań była ocena poziomu zmian jakości mrożonych truskawek składowanych w warunkach fluktuacji temperatury oraz weryfikacja H_0. Poziomy badanych cech w czasie kształtowały się jako średnia arytmetyczna poziomów tych cech uzyskiwanych w warunkach skrajnych. Materiał badawczy stanowiły mrożone truskawki przechowywane w temperaturze stałej –18°C i –25°C oraz zmiennej –18°C/–25°C z 48-godzinnym cyklem zmiany. Oznaczono w nich zawartość antocyjanów i witaminy C, kwasowość czynną i ogólną oraz wyciek rozmrażalniczy przed przechowywaniem i w cyklach czterotygodniowych przez 24 tygodnie składowania. Weryfikacja H_0 wykazała, że wartości badanych cech nie były równe wypadkowej poziomów uzyskiwanych w warunkach skrajnych, choć w niewielkim stopniu odbiegały od założonych wartości hipotetycznych. Fluktuacja temperatury powodowała w przypadku większości analizowanych cech nieznacznie niższy poziom zmian niż wynikałoby to ze średniej arytmetycznej w temperaturach skrajnych.

Introduction

Strawberries are most often consumed as fresh fruit and processed products, such as jams, juices and frozen fruit. A large scale production of frozen strawberries is due to the seasonality of supply of these fruits, the short period of shelf life of fresh fruits and very diverse use, as a frozen product.

Freezing, which is one of the best methods for protecting strawberries before lowering their quality during long-term storage, is a time-limited. The main factors affecting the quality changes are frozen fruit storage time, temperature and its fluctuations. These factors may affect the texture, flavor, appearance, color and nutrients stored, frozen strawberries. Temperature fluctuations may result from different causes. In the case of frozen fruits, they may be a result of cold chain impact, particularly during transport and distribution and storage conditions before consumption (CRUZ et al. 2013, ABD-ELHADY 2014).

According to the recommendations by the Minister of Agriculture and Rural Development of 19th September 2003 and the standard *Wiśnie zamrożone*... PN-A-78653:1997, deep-frozen agricultural and food products should be transported and stored at constant temperature not higher than –18°C. The regulation issued by the Minister allows, however, for an increase in the temperature of frozen food by up to 3°C only for loading and unloading during transport. It is thus concluded that the aforementioned regulation does not permit temperature fluctuations during storage of frozen food. Such fluctuation is allowed, yet only at the level of ±1°C, by the standard *Towary żywnościowe*... PN-83/A-07005/Az7:1999 (KRALA et al. 2010).

Studies on the changes in the quality of frozen strawberries, resulting from undesirable conditions in the cold chain, are an important element in determining the storage stability under conditions of temperature fluctuation (CRUZ et al. 2013).

The objective of the studies was to determine the level of quality changes in frozen fruits stored under conditions of fluctuating temperature and to verify the null hypothesis, assuming that the quality changes in products stored at fluctuating temperatures is not equal to hypothetical changes constituting the arithmetic mean of the changes in products stored at constant temperatures representing the extreme values of temperature fluctuations.

Materials and Methods

The studies were carried out on a strawberry Senga-Sengana. One hundred pounds of strawberries were frozen at –38°C in a fluidized bed tunnel Unidex TZF-3A UDS, in a sharp freezer operation situated in Gronowo Górne near Elbląg. The frozen fruits were transported in the transport packages, i.e. in three-layer paper bags lined with polyethylene film, to the laboratory at Gdynia Maritime University. Transportation of frozen fruits held in a van cooled eutectic plates and lasted for about eighty minutes. In the laboratory strawberry were put into polyethylene bags (commonly used in retail sales) that contained approximately 500 g of the product. The weighing, packaging and welding of the retail packages were performed at room temperature and lasted approx. 3 minutes. The material was divided into three parts, representing the following storage variants: *A* – material stored in a chamber freezer Zanussi ZV130R at constant temperature of –18°C; *B* – material stored in a chamber freezer Zanussi ZV130R at constant temperature of –25°C; and *C* – material stored in a chamber freezer Zanussi ZV130R at variable temperature –18°C/–25°C with a 48-hour exchange cycle.

The material was stored for 24 weeks and submitted for the physical and chemical analyses before storage and at 4-week cycles during storage.

Before the analyses and except for thawing spill, strawberries were thawed at room temperature.

The physical and chemical analyses of frozen strawberries were performed by determining the content of anthocyan pigments with the method by Fuleky and Francis (*Technologia chłodnictwa...* 1995), active acidity according to *Przetwory owocowe i warzywne...* PN-90/A-75101/06, total acidity according to *Przetwory owocowe i warzywne...* PN-90/A-75101/04, volume of thawing spill (JARCZYK et al. 1986), and the content of vitamin C with the spectrophotometric method according to *Produkty spożywcze...* PN-A-04019:1998. All measurements and markings were performed in nine replications.

While developing an indicator that would describe the changes provoked by storage temperature fluctuations, it was assumed that the quality changes in stored products at fluctuating temperatures were not equal to hypothetic

changes constituting the arithmetic mean of changes that occur in products stored at constant temperatures representing the extreme fluctuation temperatures. The model that would allow for a verification of the assumption on the average increment in a quality change (P%) caused by temperature fluctuations was established based on a relation described with the following equation (PUKSZTA 2014):

$$P\% = \frac{1}{n}\sum_{i=1}^{n} R \tag{1}$$

where:
$P\%$ – indicator of the level of changes induced by fluctuation; it determines the average increment of quality change,
R – relative difference between the real and hypothetical value of trait [%].

$$R = 100 - \left(\frac{Z}{M} \cdot 100\right) \tag{2}$$

where:
Z – real level of trait for variable temperature,
M – hypothetical level of trait for variable temperature.

$$M = 0.5 \cdot (C_W + C_N) \tag{3}$$

where:
C_W – level of trait at higher temperature,
C_N – level of trait at lower temperature.

Results and Discussion

Freezing and storage of frozen strawberries induce transformations that result in:

– a reduction of the sensory value due to a partial degradation of anthocyan pigment, browning and changes in taste and smell substances,

– texture changes in the products that cause a decrease in water retention capacity,

– changes in the nutritional value due to a reduction in vitamin C content.

The rate of these transformations is determined, among others, by time and a constant product storage temperature (PUKSZTA and PALICH 2006).

During preservation and storage of strawberries, anthocyan pigments undergo degradation.

The results of the studies on the changes in the concentration of anthocyan pigments in frozen strawberries stored at different temperatures are presented in Table 1.

Table 1

Content of anthocyans in frozen strawberries in relation to time and temperature of storage

Storage time [weeks]	Contente of anthocyans [mg/100 g]											
	storage temperature											
	–18°C			–25°C			–18°C/–25°C					
	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	M	R	P%
	content of antocyans befor storage 8.10 mg/100 g											
4	7.58	6.4	0.99	7.95	1.9	0.88	7.18	11.4	0.94	7.77	7.53	11.84
8	7.06	12.8	0.96	7.15	11.7	0.93	6.25	22.8	0.70	7.11	12.03	
12	6.25	22.8	0.85	6.55	19.1	0.52	5.70	29.6	0.70	6.40	10.94	
16	5.60	30.9	0.31	5.90	27.2	0.54	5.02	38.0	0.25	5.75	12.70	
20	4.85	40.1	0.43	5.57	31.2	0.55	4.55	43.0	0.62	5.21	12.67	
24	4.25	47.5	0.28	5.30	34.6	0.52	4.05	50.0	0.23	4.78	15.18	

$\bar{Y}$ – arithmetic mean $n = 9$, Δ% – percentage change in the level of examined trait in relation to the initial level, Se(Y) – standard deviation, M – hypothetical average level of trait for variable temperature, R – relative difference between the real and hypothetical value of trait [%], P% – indicator of the level of changes induced by fluctuation; it determines the average increment of quality change.

In all the tests carried out during the storage of the test material was observed lowering of the anthocyanin content. The rate of degradation of anthocyanins was different in relation to the storage temperature.

Irreversible transformations of anthocyan pigments may result from oxidative polymerization, which causes a change from the red, natural colour of fruits to ared-russet colour which is typical of long-stored products. The activity of phenoloxidase enzymes that are found in fruits may also be a factor which induces degradation of anthocyans. Anthocyans are not direct and proper substrates for phenoloxidases which may be oxidized indirectly by quinones generated by an enzymatic oxidation of chlorogenic acid or catechin. Further stages of oxidation and polymerization may occur without enzymes. The lack of enzymes or their inactivation as observed in frozen food causes a process of pigment degradation to occur mainly as the oxidation of vitamin C. Ascorbic acid may reduce quinones and inhibit the process of oxidative polymerization of anthocyans. However, in products rich in vitamin C, degradation of anthocyan pigments is a more rapid process. The main role is attributed to a hydroperoxide which is produced in the process ofnon enzy-

matic oxidation of ascorbic acid to dehydroascorbic acid, particularly with the presence of copper ions, or as a result of an interaction of anthocyans with the products of ascorbic acid degradation. These processes are substantially accelerated at fluctuating storage temperatures (HORUBAŁA 1975, *Technologia chłodnictwa...* 1995).

According to WROLSTAD et al. (1970) and SOKOŁOWSKA et al. (1969), anthocyan pigment destruction is impacted by copper and iron ions, light, ascorbic acid and some products of sugar degradation. The impact of temperature on this process could be indirect by changing the quantity of free water, pH, and sublimation of ice or the concentration of l-ascorbic acid.

Table 2

Active acidity of frozen strawberries in relation to time and storage temperature

Storage time [weeks]	Active acidity [pH]											
	storage temperature											
	–18°C			–25°C			–18°C/–25°C					
	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	M	R	P%
	active acidity before storage 3.65											
4	3.63	0.5	0.02	3.63	0.5	0.02	3.61	1.1	0.03	3.63	0.55	1.26
8	3.62	0.8	0.02	3.63	0.5	0.02	3.58	1.9	0.04	3.62	0.97	
12	3.60	1.4	0.04	3.62	0.8	0.01	3.56	2.5	0.03	3.61	1.39	
16	3.58	1.9	0.03	3.61	1.1	0.02	3.55	2.7	0.02	3.60	1.25	
20	3.55	2.7	0.04	3.59	1.6	0.02	3.51	3.8	0.03	3.56	1.40	
24	3.49	4.4	0.05	3.57	2.2	0.02	3.46	5.2	0.04	3.53	1.98	

* key cf. the Table 1

Table 3

Total acidity of frozen strawberries in relation to time and temperature of storage

Storage time [weeks]	Total acidity [g citric acid/100g product]											
	storage temperature											
	–18°C			–25°C			–18°C/–25°C					
	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	M	R	P%
	total adcidity before storage 0,9387 g/100g											
4	1.0240	9.1	0.0006	0.9600	2.3	0.0004	1.0371	10.5	0.0007	0.9920	-4.55	-3.58
8	1.0835	15.4	0.0009	1.0415	11.0	0.0005	1.1262	20.0	0.0008	1.0861	-3.69	
12	1.1429	21.8	0.0007	1.1080	18.0	0.0007	1.1600	23.6	0.0008	1.1533	-0.59	
16	1.1887	26.6	0.0008	1.1745	25.1	0.0004	1.2131	29.2	0.0007	1.1771	-3.06	
20	1.2016	36.2	0.0007	1.2112	29.0	0.0005	1.3156	40.2	0.0005	1.2064	-3.22	
24	1.3881	47.9	0.0009	1.2785	36.2	0.0005	1.4181	51.1	0.0009	1.3333	-6.36	

* key cf. the Table 1

Acidity of food products is one of the most important criteria used to evaluate their quality. It may be determined as a quantity of acid compounds produced with electrolytic dissociation and neutralized by titration with base or phmetrically as the concentration of hydrogen ions. For the evaluation of strawberries, changes in total acidity and in pH may be an indicator of their quality (*Technologia chłodnictwa...* 1995).
The course of changes in active and total acidity during storage of frozen strawberries is presented in Table 2 and Table 3.

Analysis of the results showed a reduction in pH values and an increase in the total acidity of the fruit stored at a variable temperature and constant –18°C and –25°C.

The changes in acidity during the storage of strawberries are related to an increase in the concentration of organic and inorganic salts in unfrozen water. These salts may precipitate changes, thus affecting the acidity of environment. Organic acids and their salts constitute natural buffer solutions. When specific salts precipitate, a buffer solution may decrease its volume and lose, partially or totally, its buffer capacity.

A partial hydrolysis of pectins and release of the active groups of galacturonic acid (the basic components of these polysaccharides) may have occurred under the influence of organic acids. Although at low temperatures these processes are limited, they may have contributed to an increase in the acidity of the stored products (*Chemia żywności...* 2000, HORUBAŁA 1975).

During storage of frozen strawberries, their cellular and tissue structure is affected, leading to a spill during thawing.

The volumes of thawing spill from frozen strawberries in relation to time and storage temperature are presented in Table 4.

Table 4

Thawing spill from frozen strawberries in relation to time and storage temperature

Storage time [weeks]	Thawing spill [cm^3/100 g]											
	storage temperature											
	–18°C			–25°C			–18°C/–25°C					
	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	M	R	P%
	thawing spill before storage 18.50 cm^3/100 g											
4	18.63	0.5	0.61	18.80	1.6	0.35	20.00	8.1	0.44	18.70	-6.95	-16.23
8	19.60	5.9	0.52	18.90	2.2	0.46	21.80	17.8	0.56	19.25	-13.25	
12	21.20	14.6	1.22	19.50	5.4	0.56	23.50	27.0	0.62	20.35	-10.07	
16	23.20	25.4	0.76	20.40	10.3	1.04	25.80	39.5	0.95	21.80	-5.50	
20	25.60	38.4	0.85	20.50	10.8	0.46	29.20	57.8	1.35	23.05	-26.68	
24	28.20	52.4	0.82	21.90	18.4	0.61	33.80	82.7	1.22	25.05	-34.93	

* key cf. the Table 1

The results indicate a steady increase in the size of the thawing spill with storage time. The greatest rate of growth thawing spill characterized by strawberries stored under conditions of temperature fluctuations, the smallest and at constant -25°C.

A thawing spill is generated by a transformation of the crystal arrangement that is caused by sublimation of smaller ice crystals and flow of water vapour towards bigger crystals stimulated by a difference in partial pressures. This induces an increase in the average crystal size, leading to a decrease in the quality of the stored products. The constant increase in the size of ice crystals results in an ongoing destruction of the cell walls and in an increase in the volume of thawing spill. The process of re-crystallization is intensified by temperature fluctuations during storage. Re-crystallization occurs even in products stored at a relatively constant temperature, although its magnitude is minor and depends on the time and temperature of storage (PUKSZTA and PALICH 2006).

Krala et al. also pointed to the influence of temperature fluctuations on the size of the thawing spill fruit. In a study of the sensitivity of cherries on storage temperature fluctuation, they found that significant temperature fluctuations storage of frozen cherries promote recrystallization of ice and increase the damage to their texture, thereby increasing the thawing spill (KRALA et al. 2010).

Changes in the nutritional value due to a decrease in the content of vitamin C are one of the pathways leading to a reduction of the quality of frozen food products. This vitamin plays an important role in human nutrition and is assumed to be an indicator of the behaviour of other micronutrients in fruit and vegetable products during storage (HORUBAŁA 1975, SOKOŁOWSKA et al. 1969).

The changes in the content of vitamin C in frozen strawberries are presented in Table 5.

Table 5

Content of vitamin C in frozen strawberries in relation to time and temperature of storage

Storage time [weeks]	Content of vitamin C [mg/100 g]											
	storage temperature											
	–18°C			–25°C			–18°C/–25°C					
	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	$\bar{Y}$	Δ%	Se(Y)	M	R	P%
	content of vitamin C before storage 61.23 mg/100 g											
4	59.20	3.3	4.03	60.70	0.9	2.98	59.60	2.7	3.92	59.95	0.58	2.42
8	59.00	3.6	3.83	60.10	1.8	3.52	59.30	3.2	3.81	59.55	0.42	
12	57.40	6.3	3.92	59.50	2.8	3.28	57.9	5.4	2.98	58.45	0.94	
16	56.30	8.1	3.14	58.61	4.3	3.47	55.72	9.0	3.52	57.46	3.02	
20	55.92	8.7	2.92	57.98	5.3	3.22	55.11	10.0	3.20	56.95	3.23	
24	53.88	12.0	3.41	57.25	6.5	3.93	52.05	15.0	4.13	55.57	6.33	

* key cf. the Table 1

During storage, the test products in all variants the temperature found a steady decline of the contents of vitamin C. The dynamics of this ratio varied depending on the storage option. Highest growth rate of the content of L-ascorbic acid showed strawberries stored in a variable temperature conditions.

The changes in the content of vitamin C during frozen storage of fruits and also indicates Skupień and Ancos et al. In blueberries stored for one year at temperature –25°C, Skupień state vitamin C losses of up to 72%, while de ANCOS et al., loss of vitamin after a year of storage at –20°C varieties of raspberry tagged at up to 55% (MICHALCZYK and KUCZEWSKI 2012).

The processes of oxidation and destructive impact of specific enzymes are the major pathways of vitamin C transformation. The impact of both factors is substantially intensified with a fluctuating storage temperature, which was confirmed by the present study. In addition, it was found that the fluctuation of temperature during the storage of frozen products significantly increased their loss-in-weight. This was most probably due to superficial ice sublimation that, because of a limited migration of water in the products, led to an extremely dehydrated layer with a porous structure. Sublimated ice is replaced by air, which – with a well-developed porous layer – may inevitably result in an intensification of oxidation processes, for instance, of L-ascorbic acid (PUKSZTA 2009). The increase in temperature from –25°C to –18°C which strawberries stored at fluctuating temperature were exposed to, contributed to an increase in the speed of enzymatic reactions and caused vitamin C degradation. According to MUÑOZ-DELGADO (1978), an increase of temperature by 10°C (from –20°C to –10°C) results in a 3.5–4-fold acceleration of enzymatic reactions responsible for vitamin C degradation. This thesis was reflected in a reduction of the content of L-ascorbic acid detected in strawberries stored at variable temperature and in a significantly lower reduction of vitamin C concentration at constant temperature, particularly at -25°C. Thus, reduction of storage temperature has a direct impact on a deceleration of enzymatic reactions (KLIMCZAK and IRZYNIEC 1997).

The studies also demonstrated that, from a quality perspective, it was more beneficial to store the product at extremely higher constant temperature of -18°C than at a fluctuating temperature of –18°C/–25°C. The level of transformations in strawberries stored at –18°C was lower than in the fruits stored at a variable temperature of –18°C/–25°C. (Tables 1, 2, 3, 4, and 5).

Cruz et al. in research on the effects of temperature fluctuation on the quality of frozen strawberries also found that it is preferable to store strawberries in a constant temperature than under temperature fluctuations (CRUZ et al. 2013).

The impact of temperature fluctuations on the direction and range of the examined quality traits was analysed based on the values and marks of the indicator of changes caused by fluctuation *P*%. The null hypothesis assumed that the quality changes of strawberries stored at a fluctuating temperature were not equal to the hypothetical changes which constituted the arithmetical mean of changes in the product stored at a constant temperature representing the extreme values of temperature fluctuations. With these assumptions, the indicator *P*% had large numerical values ($P>10$) when the difference between the hypothetical and real values was large. The mark of *P*% indicator depended on the deviation of real values from hypothetical values. If real values deviate towards a higher extreme parameter, the indicator of changes caused by fluctuation *P*% has a minus character.

The verification of the null hypothesis demonstrated that the values of the examined traits (Tables 1–5) were not equal to the resultant of the levels recorded under extreme conditions, though for the majority of the analysed quality parameters they slightly diverged from the assumed hypothetical values. The exception was the level *P*% for the changes in the volume of thawing spill and the content of anthocyans, showing that the temperature fluctuations caused a substantial intensification of these processes in stored strawberries (Table 1 and Table 4). In the case of active acidity, total acidity and vitamin C concentration, it was found that the deviations of the real values from the hypothetical ones were minor, which indicated a negative impact of temperature fluctuations on the changes in these quality parameters (Table 2, Table 3, and Table 5). In addition, a negative character of *P*% indicator for the changes in total acidity and volume of thawing spill indicates a deviation of the real values recorded at fluctuating temperature towards the values recorded during storage of strawberries at extremely higher temperature, i.e. –18°C (Table 3 and Table 4).

The inclusion of the fluctuation of parameters in the analysed kinetic arrangement and, therefore, the application of a statistical model, allowed for a positive verification of the null hypothesis assuming a lack of negative impact of temperature fluctuations on the storage life and nutritional quality of frozen strawberries.

Conclusions

1. The changes in the quality of frozen strawberries stored at fluctuating temperature are not equal to the hypothetical changes constituting the arithmetic mean of the transformations occurring in products stored at constant temperatures representing the extreme values of temperature fluctuations.

2. Assuming the quality of frozen strawberries, it is more beneficial to store them at an extremely higher temperature, i.e. -18°C, than at a variable temperature of-18°C/-25°C.

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EFFECT OF THE SIZE OF TRITICALE KERNEL ON MILLING ENERGY CONSUMPTION, FLOUR YIELD AND GRANULOMETRIC COMPOSITION OF FLOUR

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K e y w o r d s: triticale, kernel size, energy consumption of milling, particle size, flour.

A b s t r a c t

This study assessed the effect of kernel size on the milling properties of triticale grain, particularly on the flour yield, energy consumption of the milling process and the granulometric composition of flour. The samples of two spring triticale varieties were segregated by kernel size into four kernel-size fractions. The grain fractions were milled in a Brabender Quadrumat Jr. roll mill.

The kernel size had a significant effect on flour yield and on the milling efficiency coefficient. The milling yield increased with an increased triticale kernel size. The energy required to produce 1 kg of flour from triticale grain increased gradually, assuming the lowest value for the smallest kernels and the highest value for the kernel thickness fraction from 2.75 to 3.0 mm. The kernel size was found to have an effect on the protein and ash content in the flour. Flour milled from the smallest-kernel fraction had a significantly lower protein content and a higher ash content. Segregating grain into kernel-size fractions before milling caused significant changes in the minimum and average size of the flour particles.

WPŁYW WIELKOŚCI ZIARNA PSZENŻYTA NA ENERGOCHŁONNOŚĆ PRZEMIAŁU, WYDAJNOŚĆ I SKŁAD GRANULOMETRYCZNY MĄKI

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S ł o w a k l u c z o w e: pszenżyto, wielkość ziarna, energochłonność przemiału, wielkość cząstek, mąka.

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Abstrakt

Celem badań była ocena wpływu wielkości ziarniaków na właściwości przemiałowe ziarna pszenżyta, w szczególności na energochłonność przemiału oraz wydajność i skład granulometryczny mąki. Ziarno dwóch odmian pszenżyta jarego było segregowane na podstawie wielkości na cztery frakcje rozmiarowe. Każdą z uzyskanych frakcji ziarna mielono w młynie walcowym Brabender® Quadrumat Jr.

Wielkość ziarniaków miała znaczący wpływ na wydajność mąki i współczynnik efektywności mielenia. Wraz ze wzrostem wielkości ziarna pszenżyta zwiększała się wydajność mąki. Energia wymagana do wyprodukowania 1 kg mąki z ziarna pszenżyta stopniowo rosła, przyjmując najniższą wartość dla ziaren najmniejszych i najwyższą wartość dla frakcji ziaren o grubości od 2,75 do 3,0 mm. Stwierdzono wpływ wielkości ziarna na zawartość białka i popiołu w uzyskanej mące. Mąka z ziaren frakcji najmniejszych charakteryzowała się istotnie niższą zawartością białka i wyższą zawartością popiołu w porównaniu z mąką z pozostałych frakcji. Segregacja ziarna przed przemiałem na frakcje rozmiarowe spowodowała istotne zmiany w minimalnej i średniej wielkości cząstek uzyskanych mąk.

Introduction

Triticale is hybrid obtained by crossing wheat and rye. Although triticale is utilized as feed for animals, it also has great potential to be exploited as an alternative cereal in human nutrition (BOROS 2006), particularly in the production of bread and other food products (PÉREZ et al. 2003, OLIETE et. al. 2010). Due to its agronomic (resistance to wheat and rye diseases and to lodging, good winter hardiness characteristics, lower soil requirements and better resistance to drought compared to wheat) and nutritional advantages (a good source of protein with beneficial amino acid composition), triticale is acknowledged as a cereal which can help in combating world hunger (PISULEWSKA et al. 2000, AMMAR et al. 2004, MERGOUM et al. 2009, MCGOVERIN et al. 2011).

There are reports in the literature on the relationship between wheat kernel size and flour yield and flour ash. Large-kernel samples have significantly higher flour yield than smaller kernels (DZIKI and LASKOWSKI 2004, BAASANDORJ et al. 2015). However, GAINES et al. (1997) demonstrated that milling qualities were independent of kernel size.

Other studies have supported the hypothesis that kernel size plays a role in the physicochemical properties of wheat. DZIKI and LASKOWSKI (2004) reported that kernel size has an influence on bulk density and PSI hardness index and large kernels had the lowest values of PSI hardness index and ash content. KONOPKA et al. (2007) reported that kernel size has an influence on grain protein composition. The albumin/globulin and glutenin fractions showed a trend to reduce with diminishing kernel size. MORGAN et al. (2000) indicated significant positive correlations between kernel size and farinograph indicators and baking water absorption. LI et al. (2008) demonstrated that kernel hardness and water absorption of flour increased with increasing kernel thickness and decreasing kernel specific density. In turn, OHM et al. (1998)

reported that bread volumes had significant negative correlations with single weight and single kernel diameter.

Kernel size is of interest not only in wheat, but also in other cereals, such as barley, oat and rice (DOEHLERT et al. 2002, SÝKOROVÁ et al. 2009). Relatively little is known about the effect of triticale kernel size on milling and the granulometric composition of flour. Although the size of cereal grain has been already studied, it was connected to the granulometric composition of flour obtained from kernels of various sizes. The particle size distribution of flour is a very important property from a technological point of view, since it affects subsequent processing steps. The objective of this study was to determine the effect of kernel size on milling properties of triticale grain, especially on the milling efficiency, energy-consumption and the particle size distribution of flour.

Materials and Methods

The grains of two Polish (soft) triticale cultivars: Andrus and Milewo (a spring cv.), were the subject of the study. Triticale was cultivated at the Experimental Farm (53°73'N 20°41'E) of the University Warmia and Mazury, Olsztyn, in north-eastern Poland. Kernels of each cultivar were cleaned using a "cereal cleaning mill" (winnower) and a separator Type SŻD, Sadkiewicz® Instruments, Poland. Grain after harvest was dried to a moisture content below 15% and screened on sieves with rectangular openings widths of 2.50, 2.75, 3.00 mm using a sieve shaker Analysette 3 Pro., Fritsch®, Germany. Four kernel fractions were obtained, with respective thickness > 3.00 (F_1); 3.00 > F_2 > 2.75; 2.75 > F_3 > 2.50 and F_4 < 2.50 mm. Shriveled and broken kernels were discarded before sieving. Thousand kernel weight (TKW) was measured for each sample with the use of an electronic kernel counter (Kernel Counter LN S 50A, Unitra Cemi, Poland) and an electronic scale WPE 120 (Radwag, Poland d = 2 mg).

The samples of kernels (105 g ± 0.10 g) from each triticale kernel fraction (15% moisture content, wet basis) were weighed on a WLC 2/A1 electronic scale (d = ±10 mg) (Radwag®, Poland) and were milled using an a Quadrumat® Junior Mill (Brabender®, Germany). The energy consumption of the milling process was determined (WARECHOWSKA 2014) and the coefficient of milling efficiency K' (kJ kg^{-1}) (GREFFEUILLE et al. 2006) was calculated using the following formula:

$$K' = \frac{E_c - E_s}{m} \tag{1}$$

where:
E_c – the total energy consumed [kJ]
E_s – energy in idle mode [kJ]
m – mass of flour [kg].

Flour moisture was determined on duplicate samples by oven drying (Type UFB 500, Memmert® GmbH+ Co. KG, Germany) 5 g for 2 h at 135°C and then allowing the samples to cool before weighing. The ash content in the flours was obtained after milling (*Determination of ash*... ICC STANDARD NO. 104/1). The protein content in triticale flours was determined by the Kjeldahl method (*Determination of crude*... ICC STANDARD NO. 105/2) with a KjelFlex K-360 (Büchi, Germany).

The particle size distribution of flour received from the mill was obtained with Laser Diffraction Analysis (LDA) with a Malvern Mastersizer 2000 (version 5.22, Malvern Instruments Ltd, Malvern, UK). The measurement was started within 20s after the placement of the specimen in the sample dispersion unit. The result of the measurement was expressed as the mean value from six separate repetitions. On this basis, the average particle size of flour (d_{avg}) was determined as a general parameter characterizing the granulometric composition. It was calculated as the sum of the products of the volumetric part (φ_i) and the average size of each fraction (d_i) with the following formula (VELU et al. 2006):

$$d_{avg} = \sum_{i=1}^{n} \varphi_i d_i \tag{2}$$

where:
φ_i – share of the size fraction i in the studied sample [kg kg^{-1}],
d_i – average size of fraction i particles [μm].

The sieve mesh sizes were also calculated corresponding to the passage of 10%, 50% and 90% volume of the sample respectively $d(0.1)$, $d(0.5)$ and $d(0.9)$. They were used as indexes of the smallest, median and maximum particle size of flour, respectively. The relative width of particle size distribution (SPAN) was determined as:

$$\text{SPAN} = \frac{d(0.9) - d(0.1)}{d(0.5)} \tag{3}$$

The data was statistically analyzed and a variance analysis was performed. The significance of differences between the means was evaluated with Tukey's

test. The statistical calculations were performed with STATISTICA® for Windows v. 10 (StatSoft Inc.). The statistical hypotheses were tested at a significance level of $p = 0.05$.

Results

The share of fraction triticale grains and thousand kernel weight is demonstrated in Table 1. Each of the triticale cultivars had a similar share percentage of individual grain fractions. Kernels of thickness >3.00 mm predominated, and their content ranged from 52% to 60% (cv. Milewo and Andrus, respectively). The mean thousand kernel weight (TKW) was observed to decrease linearly for particular fractions from 50.5 (large kernels) to 22.5 g (small kernels). TKW values decreased by about 55% from large to small kernels.

Table 1

Fractional share and thousand kernel weight

Grain fraction	Share of fraction [%]	TKW [g]
Cultivar		
Andrus		
F_1	60.0^c	52.0^d
F_2	10.0^a	43.0^c
F_3	21.0^b	32.0^b
F_4	9.0^a	23.0^a
Milewo		
F_1	52.0^c	49.0^d
F_2	11.0^a	39.0^c
F_3	22.0^b	30.0^b
F_4	14.0^a	22.0^a
Fraction		
F_1	56.0^c	50.5^d
F_2	10.5^a	41.0^c
F_3	21.0^b	31.0^b
F_4	11.5^a	22.5^a

a, b, c – means followed by the same letter in the column do not differ from each other by Tukey test ($P<0.05$).

Kernel size had a significant effect on the flour yield (Table 2). The flour yield (FY) increased with increasing triticale kernel size, regardless of genotype. The flour yield was highest when the largest kernels were milled (62.3% on average) and it was the lowest for small kernels (57.5% on average).

Table 2

Effect of kernel size on flour yield and quality characteristics

Grain fraction	FY [%]	FAC [%]	FPC [%]	$d(0.1)$ [µm]	$d(0.5)$ [µm]	$d(0.9)$ [µm]	d_{avg} [µm]	SA [m^2Wm^{-3}]	SPAN [-]
Cultivar									
Andrus									
F_1	61.9^d	0.58^b	10.70^b	20.07^b	127.31^b	297.07^b	143.43^b	0.182^b	2.180^a
F_2	60.7^c	0.53^a	10.10^a	18.49^a	114.90^a	290.87^b	135.15^a	0.198^a	2.370^a
F_3	58.1^b	0.57^{bc}	10.00^a	18.42^a	113.72^a	298.63^b	136.74^a	0.197^a	2.460^a
F_4	55.4^a	0.64^c	10.20^a	18.15^a	113.04^a	287.51^a	134.20^a	0.201^a	2.380^a
Milewo									
F_1	63.3^c	0.52^{bc}	12.50^b	21.41^b	127.08^b	311.00^b	147.48^b	0.159^a	2.280^a
F_2	61.7^b	0.50^a	12.00^a	19.74^b	120.89^b	303.47^a	141.71^b	0.180^a	2.347^a
F_3	61.2^b	0.54^b	11.80^a	20.76^b	128.50^b	307.24^a	146.49^b	0.161^a	2.229^a
F_4	59.7^a	0.63^c	11.90^a	18.27^a	110.56^a	307.66^a	138.20^a	0.193^b	2.617^b
Fraction									
F_1	62.6^c	0.55^a	11.60^b	20.74^b	127.19^b	304.03^a	145.45^b	0.170^a	2.230^a
F_2	61.2^{bc}	0.52^a	11.05^a	19.12^a	117.90^b	297.17^a	138.43^a	0.189^a	2.360^a
F^3	59.7^b	0.56^a	10.90^a	19.59^a	121.11^b	302.94^a	141.62^a	0.179^a	2.340^a
F_4	57.5^a	0.64^b	11.05^a	18.21^a	111.80^a	297.59^a	136.20^a	0.197^a	2.500^a

a, b, c, d – means followed by the same letter in the column do not differ from each other by Tukey test ($P<0.05$).

For different kernel size fractions, the flour quality characteristics were also evaluated. The flour ash content (FAC) ranged from 0.52% for the fraction 2.75–3.00 mm (F_2) to 0.64% for small kernels (F_4). The flour ash content of the fraction 2.00–2.50 mm was significantly higher ($p < 0.05$) than the flour ash contents of other fractions. Small kernels had an approx. 23% increase in flour ash content compared to the kernels from fraction F_2. Kernel size has a significant effect on the flour protein content (FPC). The protein content was found to be statistically significantly higher in the flour obtained from the largest kernel size fraction (11.60% on average) compared to the flours from smaller kernels. The protein content was higher in the flour obtained from the largest kernel size fraction (11.60% on average) than the flours from smaller kernels.

As shown in Figure 1, kernel size had an effect on the milling efficiency coefficient K'. The greatest amount of energy consumed to produce flour was for milling kernel fraction F_2 of both the Andrus and Milewo cultivars (82.9 and 84.1 kJ kg^{-1} of flour, respectively). The milling efficiency coefficient was similar for the kernels of the F_1 and F_4 fractions of each of the tested triticale varieties, thus forming a homogeneous group.

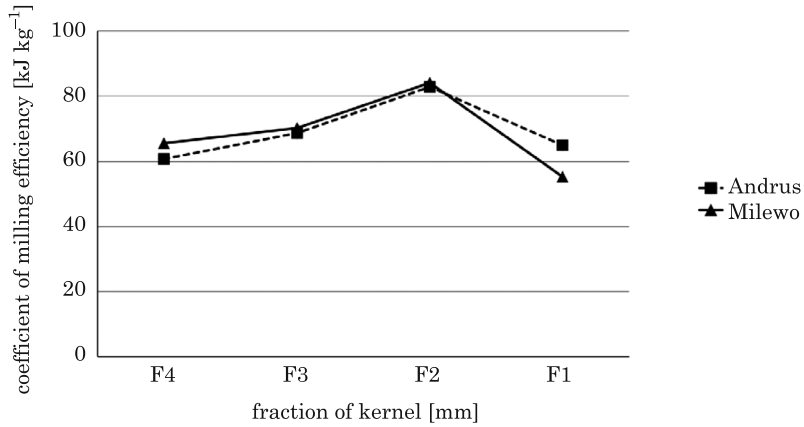

Fig. 1. The influence of kernel size on milling efficiency coefficient (K')

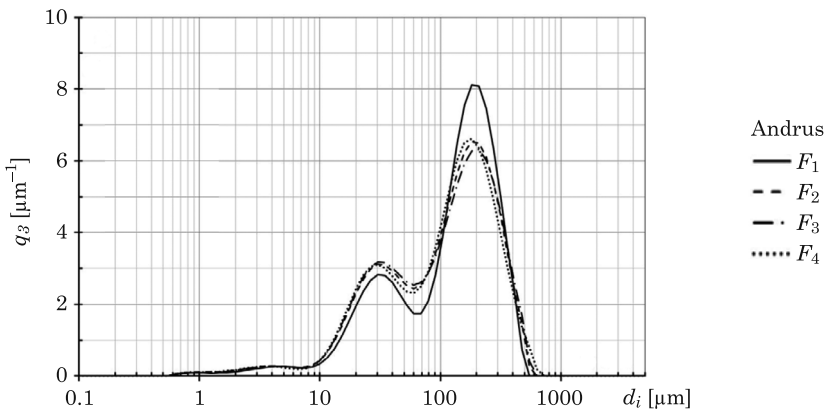

Fig. 2. Granulometric compositions of flours, obtained from different fractions of Andrus triticale grains (Brabender Quadrumat Junior Mill)

From each of milled triticale samples, a multi-modal distribution flour was obtained (Figure 2, Figure 3). The flour was almost entirely composed of two main fractions (a flour particle size of about 30 and about 200 µm) and of two residual fractions with modal values below 10 µm (about 0.8 and about 4 µm). The total share of both residual fractions for each material did not exceed 4% of the obtained flour. The proportions of the main size fractions in the flours obtained from triticale grain of the Milewo cultivar remained the same, regardless of the kernel fraction they were obtained from. A different result was found for the Andrus cultivar. From the kernel fractions from F_2 to F_4, flours were obtained which had a granulometric composition similar to that

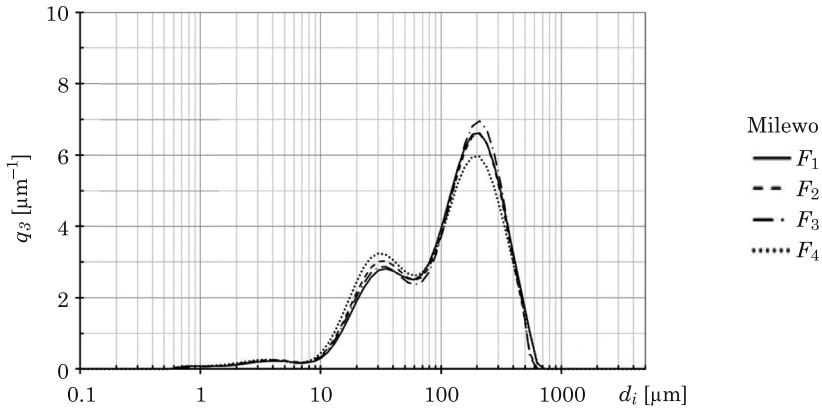

Fig. 3. Granulometric compositions of flours, obtained from different fractions of Milewo triticale grains (Brabender Quadrumat Junior Mill)

of the flours from the Milewo cultivar grain. By milling the largest kernel size fraction, flours were obtained which had different proportions of the main size fractions (Figure 2) – the proportion of the 200 µm fraction increased in relation to the 30 µm fraction. The minimal and the average size of the particles of flour and the median for triticale cultivars depended on the kernel size of the milled grain. The mentioned parameters were highest when flour was obtained from the largest kernels (F_1) and were the lowest when flour was obtained from small kernels (F_4). For the flour obtained from the remaining kernel size fractions (F_2, F_3), the differences in the parameters $d(0.1)$, $d(0.5)$ and d_{avg} were not statistically significant (Table 2). An analysis of the flour specific surface area (SA) showed it to assume significantly different values for milled thick kernels (F_1) of the cultivar Andrus and for the milled smallest kernels (F_4) of the Milewo cultivar. The flour specific surface area value does not depend on kernel size, if the cultivar is not taken into consideration.

The SPAN of the granulometric compositions of the obtained flours formed one homogeneous group. A difference was observed only for the granulometric composition of the flours obtained from the F_4 triticale kernel fraction (the cultivar Milewo) – by milling this kernel fraction, the flour which had the least homogeneous composition was obtained (2.617).

Discussion

Kernel size had a significant effect on most of the tested characteristics of both the triticale grain and the flour obtained from the grain. The thousand kernel weight of triticale increased with increasing kernel size. Many studies

concerning wheat show similar results (KONOPKA et al. 2007, BAASANDORJ et al. 2015). The lower weight of small kernels is connected with the endosperm being filled with proteins and starch to a lesser degree. During the initial stage of grain development, the endosperm cells are filled with starch granules to a lesser degree than during the final stage. The protein weight fraction is higher during the initial stage of grain development than during the final stage. This is connected with kernel size. Although during the initial stage of grain development the kernels are smaller, during the later stage they mature and become thicker with the endosperm cells and starch granules becoming larger (LI et al. 2013).

Flour yield increased with increasing triticale kernel size. According to BAASANDORJ et al. (2015) the starchy endosperm proportion in the wheat grain may determine significant differences in flour yield between kernel size fractions. Since the endosperm proportion is higher in large kernels, they have the potential to ensure higher flour yield than small kernels. According to EDWARDS et al. (2008), there is a genetic association between starch granule size distribution and flour yield. The flour yield is higher for the wheat varieties with larger starch granules (GAINES et al. 2000). Flour yield increases with an increasing proportion of the large *A*-type starch granules to the small *C*-type starch granules in wheat grain (EDWARDS et al. 2010). According to the study by LI et al. (2013), wheat kernels of different thickness differ in the proportion of the three types of starch granules *A*, *B*, and *C*. The share of the *A*-type starch granules decreases gradually with decreasing kernel thickness, and in the wheat endosperm of minimal thickness they are not present at all. The proportion of the *B*-type starch granules in the wheat endosperm increases gradually with decreasing kernel thickness, but the proportion of the *C*-type starch granules remains at a certain stable level for wheat kernels of various thicknesses. For smaller kernel sizes, the proportions of the *A*- and *C*-type starch granules and flour yield decrease. Milling efficiency is lower for triticale than for wheat and protein loss during milling tends to be greater for triticale than for wheat (DENNETT and TRETHOWAN 2013a). According to POSNER and HIBBS (1997) the grain protein content decreases with increasing kernel size. Greater protein loss was also observed for milling small kernels, which was also confirmed by BAASANDORJ et al. (2015). In their study, the difference between the wheat grain protein content and the protein obtained from grade flour was greatest for small kernels. In the current study, the protein content in the flour obtained from the largest kernels was the highest and it differed significantly from the protein contents in the flours from the other kernel fractions, as was found by KONOPKA et al. (2007). The total grain protein data for different kernel sizes is not clear. KONOPKA et al. (2007) found the wheat grain protein content decreased with decreasing kernel size and the

flours obtained by milling the extreme kernel fractions differed in protein content and composition. In that study, the flours obtained from the largest kernels had the highest protein contents.

Lower flour ash content indicates less contamination with bran and germ (KIM and FLORES 1999). Flour ash content depends on both flour extraction percentage and total triticale ash content but also on ash distribution within the kernel which, in turn, depends on environmental conditions (LORENZ 1977, ANDO et al. 2002, RHARRABTI et al. 2003). The ash content in flour obtained from the smallest triticale kernels was much higher than for the other kernel fractions, which confirms the results of the former studies (DZIKI and LASKOWSKI 2004, BAASANDORJ et al. 2015). The high flour ash content for the fraction 2.0–2.5 could be due to the low proportion of endosperm relative to the bran and aleurone layer, which are rich in ash. According to BAASANDORJ et al. (2015), the high ash content for flour milled from small kernels might be partly due to the fixed roll gap in a mill. As a result, less bran might be removed from small kernels, resulting in poor separation of bran and germ from the endosperm. It needs to be highlighted that the ash contents in the flours obtained from triticale are higher than in those obtained from wheat, in spite of the equal, or even lower, flour extraction rate. This is the result not only of the bran layer being thicker in triticale compared to wheat, but also of the higher mineral content in the endosperm (DENNETT and TRETHOWAN 2013a, DENNETT and TRETHOWAN 2013b).

Measurement of *K*' obtains indications on the mechanical behavior of the grain during the milling process (GREFFEUILLE et al. 2006). Kernel size had a significant effect on the triticale coefficient of milling efficiency (*K*'). The energy necessary to produce 1 kg of flour from triticale grain increased gradually, assuming the lowest value for the smallest kernels and the highest value for the kernel thickness fraction from 2.75 to 3.0 mm. According to FANG et al. (1998), more energy is required to mill wheat with a larger kernel size than to mill wheat with a smaller kernel size. Such a relationship may explain the comparable amount of energy being consumed to produce the same amount of flour from the largest and smallest kernel thickness fractions of triticale grain. To mill small kernels, a smaller amount of energy is consumed and the obtained flour extraction rate is the lowest, while for milling the largest kernels, a greater amount of energy is consumed and the flour extraction rate is the highest. The obtained data may also be the result of differentiated single kernel hardness for kernels of different thickness. BAASANDORJ et al. (2015) found middle-size wheat kernels to be the hardest (HI SKCS) and the small kernels to be softest. Hard wheats require a greater amount of energy to produce the same amount of flour than soft wheats (PUJOL et al. 2000, GREFFEUILLE et al. 2006).

Conclusions

The kernel size had a significant effect on flour yield. The milling yield increased with increasing the kernel size of triticale. The smallest kernels showed worse millability with lower flour yield and higher flour ash content than large-sized kernels. The energy necessary to produce 1 kg of flour was the largest for the kernel thickness fraction of 2.75–3.00 mm. Flour of triticale grain from the smallest-kernel fraction had a significantly lower protein content and a higher ash content than flour from other kernel fractions. Segregating grain into kernel-size fractions before milling caused significant changes in the minimal and the average size of the particles of the flours.

Separating small and large kernels from each other may improve both flour yield and quality and optimize the working parameters of the machines used for cleaning and milling grain in grain processing.

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AN ASSESSMENT OF RECREATIONAL POTENTIAL OF CHOSEN LAKES OF OLSZTYŃSKIE LAKE DISTRICT (WARMIA AND MAZURY, POLAND) FOR ANGLING PURPOSES

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K e y w o r d s: lakes, angling, recreational potential, natural determinants, angling management.

A b s t r a c t

Angling is one of the most popular forms of recreation in Poland. The aim of the present work was an evaluation of angling potential of chosen lakes in the Olsztyńskie Lake District. Multidimensional comparative analysis was applied in this study. The study included 19 lakes. In the final assessment lakes Tejstymy, Tumiańskie and Dadaj achieved the highest potential for angling with values of synthetic measure over 0.5. The lowest values were achieved by lakes Rzeckie, Rasząg and Kraksy Małe (under 0.2). The best rated lakes were characterized by high values of synthetic measures in both studied groups of features. It was reassumed, that the lakes with low synthetic measure of the group of natural determinants were not worth to be invested. The lakes with not fully utilized natural potential and the lakes with unutilized natural potential (especially worth to be invested) were indicated.

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OCENA POTENCJAŁU REKREACYJNEGO WYBRANYCH JEZIOR POJEZIERZA OLSZTYŃSKIEGO (WARMIA I MAZURY, POLSKA) DO CELÓW WĘDKARSTWA

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S ł o w a k l u c z o w e: jeziora, wędkarstwo, potencjał rekreacyjny, uwarunkowania przyrodnicze, zagospodarowanie wędkarskie.

A b s t r a k t

Jedną z najbardziej popularnych form rekreacyjnego wykorzystania jezior w Polsce jest wędkarstwo. W ostatnich kilkunastu latach nastąpił jego dynamiczny rozwój, który przyczynił się do opracowania systemu oceny naturalnych zbiorników wodnych pod kątem ich przydatności do tej formy rekreacji.

Celem pracy było oszacowanie potencjału rekreacyjnego wybranych jezior Pojezierza Olsztyńskiego do celów wędkarstwa. W pracy zastosowano metodę oceny opartą na analizie porównawczej uwarunkowań przyrodniczych i zagospodarowania wędkarskiego zbiorników. W badaniach uwzględniono 19 jezior. Wykazano, że największy potencjał wędkarski mają jeziora: Tejstymy, Tumiańskie oraz Dadaj, które uzyskały wartość miernika syntetycznego powyżej 0,5. Najniższe wartości miernika uzyskały jeziora: Rzeckie, Rasząg oraz Kraksy Małe (poniżej 0,2). Najwyżej ocenione akweny charakteryzowały się wysokimi wartościami mierników syntetycznych zarówno pod względem uwarunkowań przyrodniczych, jak zagospodarowania wędkarskiego. Stwierdzono, że nie warto inwestować w jeziora o niskich wartościach miernika syntetycznego dla działu uwarunkowania przyrodnicze. Wskazano jeziora o niewykorzystanym potencjale przyrodniczym, w które szczególnie warto zainwestować.

Introduction

One of the most attractive elements of natural environment commonly used for tourism and recreational purposes are lakes and their shores (HALL and HARKONEN 2006, HALL 2010). According to DEDIO (1989) and ŁAPIŃSKA (1998), lakes are those components of the environment, which decide of its attractiveness for humans. From a recreational point of view an area of water-land contact is important because of its potential for performing various recreational activities. Lakes are primary destinations for leisure, they are responsive ecosystems, sensitive to changes caused by tourism development (COOPER 2006). Multifunctional use of lakes in terms of their ecological, recreational and fishing functions contributed to increase the level of anthropopression on lakes (BNIŃSKA 1992).

Angling is a popular form of human activity, which combines mentioned above functions. According to surveys (FENCZYN 1998, SKRZYPCZAK 2005) angling constitutes the largest group of hobbyists in Poland, which has about 630 thousand registered members (PZW 2016). Angling enjoys a great interest from the society, and this fact is a result of its interdisciplinary nature. It combines many disciplines of life such as sport, tourism and relaxation (FENCZYN 1998).

The importance of angling in terms of fishery management in Poland started to rise at the end of the twentieth century. The fishery management based solely on net fishing became unprofitable (SKRZYPCZAK 2005, CZERWIŃSKI 2014, SKRZYPCZAK et al. 2014). It is worth noting that the expenses related to recreation, including angling, not apply to the general principles of economy (MICKIEWICZ et al. 2008). This is due to the fact that people (including anglers) often submit expenses associated with their hobby over other needs (SEWELL and ROSTRON 1970, WOŁOS 2000).

SOŁOWIEJ (1992), claims that any attempts at evaluating tourist space are useful and fully justified. There are many studies that describe the usability of lakes for tourism and recreation (DÁVID 2003, FURGAŁA-SELEZNIOW et al. 2007, HALL 2009, BOROMISZA 2013, TUOHINO 2015). There are some studies devoted to the impact of angling on the water environment and ichthyofauna (SKŁODOWSKI and LIPKA 2011, CZARKOWSKI et al. 2012, WOŁOS et al. 2013, WOŁOS 2014). Economic aspects of the angling were the subject of some analyses too (SIPPONEN 1998, MICKIEWICZ et al. 2008, CZERWIŃSKI 2013, WOŁOS 2014). However publications and scientific research devoted to lakes suitability for angling purposes are scarce. Intensive development of recreational fishing contributes to create the evaluation system of natural water reservoirs for their suitability for angling (SKRZYPCZAK 2005, SKRZYPCZAK et al. 2006).

The aim of the study was to evaluate suitability of chosen lakes of Olsztyńskie Lake District, Poland for angling purposes.

Study area

The study covered a group of 19 lakes situated in the communes of Biskupiec and Barczewo in the Province of Warmia and Mazury. According to the physico-geographical division of Poland into regions, the tested lakes are situated on the macroregion of Masurian Lake District, mesoregion Olsztyńskie Lake District, North-East Poland (KONDRACKI 1998). The lake district was formed during the last glacial period, known as Baltic glaciation.

Lakes with an area exceeding 10 hectares, for which data on fish stocking were available were selected for the study. Basic morphometric parameters of tested lakes in Biskupiec and Barczewo communes were shown in the Table 1.

Table 1

Morphometric parameters of studied lakes in Barczewo* and Biskupiec** communes (Province of Warmia and Mazury, Poland) (according to JAŃCZAK 1999)

Lake	Surface area [ha]	Maximum depth [m]	Average depth [m]	Lakeshore development
Pisz*	205.9	25.2	5.5	2.34
Tumiańskie*	122.2	17	6.7	1.43
Dobrąg*	103.5	8	3.5	1.39
Umląg*	91.9	9.3	3.1	1.79
Kierzlińskie*	91.5	27.9	11.5	1.57
Kiermas*	80.8	11.5	4.6	1.71
Orzyc*	62.1	44.5	11.7	1.41
Świętajno*	23.9	6.6	2.7	1.16
Łęgajny*	19.7	5	1.8	1.30
Dadaj**	976.8	39.9	12.3	3.10
Tejstymy**	198.2	33.0	10.0	1.89
Pierwój**	134.1	26.0	7.7	1.60
Jełmuń**	131.4	7.5	4.0	1.62
Stryjewskie**	67.5	6.2	2.6	1.85
Rzeckie**	59.0	29.0	6.8	2.02
Węgój**	53.7	6.0	2.1	1.52
Kraksy**	44.2	4.0	1.1	1.85
Rasząg**	30.5	5.9	2.9	1.51
Kraksy Małe**	14.1	1.7	0.8	1.35

The Masurian lake District belongs to regions were lakes are a basis for tourism development (SMITH 2003, BANASIK and BUCHOLZ 2010, *Strategia rozwoju*... 2013). In the western part of the region they are rather small lakes not suitable for sailing.

Materials and Methods

For the evaluation of angling attractiveness of lakes, a method suggested by SKRZYPCZAK (2005) was applied in this study. It allowed to obtain synthetic measures which achieve numerical values from 0 to 1. Multidimensional comparative analysis is the method in which the objects being examined are described by various features (*Regionalne aspekty*... 1999). The comparative evaluation of the potential of lakes for angling purposes was based on two groups of features: (1) natural determinants for angling and (2) angling management (Table 2) as proposed by SKRZYPCZAK (2005). Depending on what

is the impact of a given feature on the object being examined, the differentiation of stimulants (S) and destimulants (D) was done. Stimulants are those features whose high value is linked to a positive evaluation of the lake examined. Destimulants include all the features whose low value results in a positive evaluation (*Regionalne aspekty*... 1999).

Table 2

Parameters applied for the evaluation of angling attractiveness of the lakes (SKRZYPCZAK 2005)

Group of parameters	Parameter	Influence of the parameter	Weight of the parameter	Weight of the group of parameters
Natural determinants for angling	the shoreline development index	stimulant	0.10	0.60
	zone of the emergent plants-rushes 1–5 m in width [%]	stimulant	0.25	
	zone of the emergent plants-rushes > 5 m in width [%]	destimulant	0.10	
	forests (fresh and dry habitats)[%]	stimulant	0.20	
	wetlands (marshes and marshy forest) [%]	destimulant	0.10	
	water table accessibility 1–10 m – 1 point 11–20 m – 2 points 21–30 m – 3 points, etc. [points 100 m^{-1} of shoreline]	stimulant	0.25	
Angling management	angling piers 1–10 m^2 [number 100 m^{-1} of shoreline]	stimulant	0.30	0.40
	recreational piers 10.1–25 m^2 [m^2 100 m^{-1} of shoreline]	stimulant	0.10	
	variety of the stocking material [number of species]	stimulant	0.15	
	mean value of stockings [pln ha^{-1} $year^{-1}$]	stimulant	0.45	

The procedure used in the present study to evaluate the recreational potential of studied lakes was split into the following steps:

Step 1. Selection of objects (lakes) and features clustered into two groups (natural determinants for angling and angling management) describing them – this is the preparation of a matrix of observations X:

$$X = [x_{ij}] \ (i = 1, ..., n; j = 1, ..., m),$$

where:

X – matrix of observations made on the variables describing particular lakes,

n – number of lakes,

m – number of variables.

Step 2. Making all variables homogenous by transferring them into stimulants. In the case of destimulants it was done based on the following formula (*Regionalne aspekty...* 1999):

$$y_{ij} = x_{j\max} - x_{ij}$$

where:
y_{ij} – destimulant transferred into stimulant,
x_{ij} – initial, original destimulant values,
$x_{j\max}$ – maximum of the feature j in studied lakes.

Step 3. Making all diagnostic variables (stimulants and destimulants transferred into stimulants) comparable. It was done using a normalization procedure, based on standardization. The following formula was used:

$$n_{ij} = \frac{y_{ij}}{y_{j\max}}$$

where:
n_{ij} – normalized value of variable j in lake i,
$y_{j\max}$ – maximum of the stimulant variable (feature) j in studied lakes,
y_{ij} – value of the stimulant variable in lake i.

Step 4. Calculation of the synthetic measure for one group of features as weighted arithmetic mean of normalized values in the group of features according the formula:

$$\mathrm{Md}_i = \sum_{j=1}^{n} w_j n_{ij}$$

where:
Md_i – the synthetic measure for group d in lake i,
w_j – weight of the feature j in group d.

Step 5. Calculation of the final synthetic measure for angling attractiveness of the lakes as weighted arithmetic meanof synthetic measures for groups:

$$\mathrm{MS}_i = \sum_{i=1}^{l} W_k \, \mathrm{Md}_i$$

where:
k – number of the group,
W_k – weight of the group k,
MS_i – final synthetic measure for lake i.

Data concerning following features: percentage of the emergent plants--rushes of different width, percentage of forests and wetlands in the shoreline, water table accessibility, number of angling and recreational piers were based on expert judgement. The shoreline development index was taken from *Atlas jezior...* (1999). Data on fish stocking performed in lakes were received from the fish farms. The mean values of fish stocking were calculated according to the formula (SKRZYPCZAK 2005):

$$Z = \sum_{j=1}^{n} G_i k_i$$

where:

Z – the value of the stocking,

n – number of species (i) used for stocking,

G_i – the mean value of the stocking material of a species (i) per year and hectare; prices quoted by the Regional Water Management Authority in Warsaw.

k_i – the weigth of the species according the Table 3.

Table 3

The weight of the species (k) used in stockings according to SKRZYPCZAK (2005)

Fish species	k value
European eel (montee), perch, pike-perch, wels catfish, pike	8
Tench, crucian carp, burbot	5
Common carp and others	1

Results

In the group of features natural determinants for angling five lakes: Pisz, Tumiańskie, Łęgajny, Kierźlińskie and Dobrąg obtained the highest value of synthetic measure (over 0.6) and showed favorable natural conditions for angling (Figure 1a). The lakes Pisz, Tumiańskie, and Dobrąg were characterised by the high proportion of forests along the shoreline (Table 4). The lakes Łęgajny, Tumiańskie and Kierzlińskie had the best water table accessibility. The lowest (below 0.4) values of natural determinants for angling were calculated in case of five lakes: Rasząg, Kraksy Małe, Kraksy, Rzeckie and Stryjewskie mainly because of difficult water table accessibility (Figure 1a, Table 4). Moreover in four lakes (excluding Kraksy), the zone of the emergent plants-rushes over 5 m in width exceeded 20% of the shoreline.

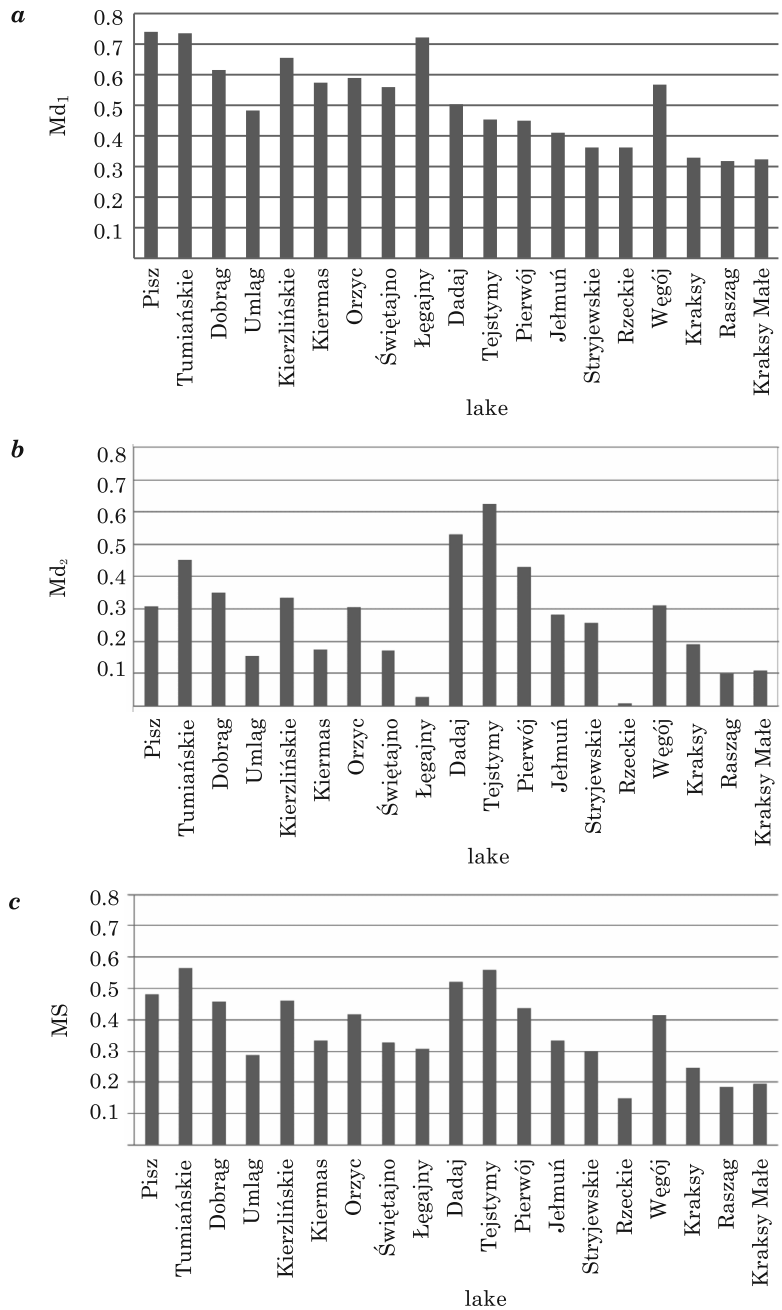

Fig. 1. Structure of the values of the synthetic measures obtained for the lakes in the section of natural conditions for angling (Md_1) (*a*), in the section of angling management (Md_2) (*b*), and the final synthetic measures of angling attractiveness (MS) (*c*) of the studied lakes from Olsztyńskie Lake District

Table 4

Normalized values of variables of two groups of analyzed features

Lake	Natural determinants for angling						Angling management			
	the shoreline development index	zone of the emergent plants-rushes 1–5 m in width	zone of the emergent plants-rushes > 5 m in width	forests (fresh and dry habitats)	wetlands (marshes and marshy forest)	water table accessibility	angling piers	recreational piers	variety of the stocking material	meanl value of stockings
Pisz	0.75	0.88	0.91	0.95	1.00	0.26	0.31	0.13	0.67	0.22
Tumiańskie	0.46	0.72	0.67	1.00	0.86	0.62	1.00	0.41	0.50	0.08
Dobrąg	0.45	0.85	1.00	0.87	0.30	0.22	0.00	0.00	1.00	0.45
Umląg	0.58	0.80	0.67	0.00	1.00	0.23	0.26	0.00	0.33	0.06
Kierzlińskie	0.51	0.86	0.91	0.41	1.00	0.47	0.20	0.00	0.83	0.33
Kiermas	0.55	0.93	0.98	0.00	1.00	0.36	0.15	0.00	0.50	0.12
Orzyc	0.45	0.77	0.67	0.80	0.72	0.20	0.48	0.24	0.50	0.14
Świętajno	0.37	1.00	1.00	0.00	1.00	0.29	0.31	0.00	0.33	0.06
Łęgajny	0.42	0.93	0.98	0.00	1.00	1.00	0.09	0.00	0.00	0.00
Dadaj	1.00	0.57	0.59	0.08	0.77	0.44	0.20	0.42	0.67	0.73
Tejstymy	0.61	0.66	0.31	0.55	0.46	0.16	0.13	0.62	0.50	1.00
Pierwój	0.52	0.83	0.83	0.00	0.10	0.39	0.15	0.10	0.33	0.72
Jełmuń	0.52	0.67	0.50	0.00	1.00	0.17	0.50	0.33	0.50	0.05
Stryjewskie	0.60	0.61	0.00	0.16	1.00	0.07	0.31	0.67	0.50	0.04
Rzeckie	0.65	0.62	0.48	0.11	0.60	0.04	0.00	0.08	0.00	0.00
Węgój	0.49	0.81	0.58	0.65	1.00	0.11	0.33	1.00	0.50	0.08
Kraksy	0.60	0.82	0.56	0.00	0.00	0.03	0.39	0.12	0.33	0.02
Rasząg	0.49	0.63	0.16	0.00	0.80	0.06	0.06	0.83	0.00	0.00
Kraksy Małe	0.44	0.75	0.46	0.00	0.19	0.12	0.20	0.13	0.17	0.02

In the group of features concerning angling management only the lake Tejstymy peaked at value of synthetic measure over 0.6 (Figure 1b). Following three lakes (Dadaj, Tumiańskie and Pierwój) received the synthetic measure over 0.4. The lowest values of synthetic measure (below 0.1) were noted in three lakes: Łęgajny, Rasząg and Rzeckie (Figure 1b). The results reflected the level of fishery management on the lakes, especially the mean value of stockings (Table 4). The mean value of fish stocking range from 0 (in lakes Rzeckie, Rasząg and Łęgajny) to 1644.5 PLN in Tejstymy Lake. The number of fish species used for stockings in particular lakes ranged from 0 (lakes Rzeckie, Rasząg and Łęgajny) to 6 (in Dobrąg).

The calculations of the final synthetic measure of lake attractiveness for angling purposes showed that lakes Tejstymy, Tumiańskie and Dadaj are the most attractive for anglers (values of final synthetic measure over 0.5) – Figure 1c. The lake Tumiańskie was characterized by high value of natural determinants for angling and moderate level of angling management (Figure 1a, b). The highest angling management synthetic measure was calculated for the lake Tejstymy while the natural determinants for angling for this lake were moderate. The lakes Rzeckie, Rasząg and Kraksy Małe had the lowest potential for angling (the final synthetic measure below 0.2) – Figure 1c.

Discussion

Lakes as a component of the environment have a significant impact for tourism and recreation. Moreover they are one of the crucial elements that influence a touristic potential of the region of their occurrence (SMITH 2003). Therefore all research which are focused on the evaluation of lake's attractiveness for tourism and recreation are valuable for local government. They are helpful in sustainable tourism management (World Lake Vision Committee 2003).

Based on Polish research in this area only DEDIO et al. (1989), SKRZYPCZAK (2005) and SKRZYPCZAK et. al. (2006) have taken attempts to assess the usefulness of water bodies for angling. Selection of lakes by their potential for recreation allows their appropriate use and create attractive destination for tourists.

In this research the highly valued lakes were characterized by favorable location (away from large urban areas and in the proximity of forests), availability of shoreline and with good access to the water table. The research of JORGENSEN and MATSUI (1997), COOPER (2006) and BOROMISZA (2013) showed that shoreline and littoral zone was a zone of highest recreation and tourism impact. Reasonably conducted fish management was an undoubted

advantage of best rated lakes. To increase their potential owners of fishing rights should plan and conduct periodic fish stocking, focused on species, popular among the anglers (ARLINGHAUS and MEHNER 2004, ARLINGHAUS et al. 2016). The most attractive species for anglers are: pike (*Esox lucius*), common carp (*Cyprinus carpio*), tench (*Tinca tinca*) and crucian carp (*Carassius carassius*) (WOŁOS 1994). SKRZYPCZAK (2005) claimed, that the regular fish stocking improves an angling attractiveness of the lake by increasing the probability of catching the fish. The second emerging topic is the investment in angling infrastructure – small bridges and piers in the shoreline of the lake as well as parking places and sanitary buildings near fishery points. This facilities will allow an easier access to the water table and increase the standard of angling conditions (WOŁOS 2000).

The possibility of indicate the influence of individual components of environment and human activity on angling suitability was the advantage of this research. On the base of these results, the owners of fishing rights can decide about profile of lake management. Therefore this method is a helpful tool to modify and improve the lakes management plans. An inclusive planning and management approach that integrates recreation fisheries within the broader scope of aquatic ecosystem management is often needed for sustainable inland fisheries (ARLINGHAUS et al. 2016). COOKE et al. (2016) characterized the scope and magnitude of inland recreational fisheries as a coupled social-ecological system.

In the present study 3 lakes (Rzeckie, Rasząg and Kraksy Małe) were classified as lakes with the lowest potential for angling because of low synthetic measure in two studied groups of features. The comparison of lakes Stryjewskie and Rzeckie showed the identical values of synthetic measure for group natural determinants for angling (0.362). Whereas the synthetic measure for angling management for these lakes differed more than thirty fold (0.255 versus 0.008). However the final synthetic measure for lake Stryjewskie was higher only twice (0.30 versus 0.15). This fact showed that it is not worth to invest in the lake with low natural determinants for angling (below 0.4). The lakes with very high value of synthetic measure for group natural determinants for angling (over 0.6) are worth to be invested even if the angling management level is relatively high (over 0.4) or moderate (over 0.3). Lakes Tumiańskie, Pisz, Kierzlińskie and Dobrąg were examples of such lakes with not fully utilized potential.

The potential of many lakes as an angling resource is often not fully realised (HICKLEY et al. 2004). The lakes with high value of synthetic measure for group natural determinants for angling (over 0.5) and with very low level of angling management (below 0.2) are good candidates to be invested at first. Even small investments may bring significant results in this case. Lakes

Łęgajny, Kiermas and Świętajno were examples of such lakes with unutilized natural potential.

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DIETARY EFFECT OF SUPPLEMENTATION WITH AMARANTH MEAL ON GROWTH PERFORMANCE AND APPARENT DIGESTIBILITY OF RAINBOW TROUT *ONCORHYNCHUS MYSKISS*

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K e y w o r d s: *Oncorhynchus mykiss*, *Amaranthus cruentus*, digestibility, chromic method.

A b s t r a c t

The aim of the this study was the to assessment of use the amaranth meal in feed for rainbow trout *Oncorhynchus mykiss*. Two experimental feeds contained 5.0% and 10.0% of amaranth meal were prepared and compared to reference diet (commercial feed) containing similar amounts of specific nutrients. Initial body wet weight of experimental trout was 524.8 ± 28.5 g and mean length of 35.2 ± 0.6 cm. Feed was offered in ration between 0.50–1.71% of fish biomass (calculated by software) of respective group for 21 days. The validation of chromic method to analyze digestibility of fish diet components was done and the linear regression formula $Y = 0.0142X + 0.075$ was determined for chromium oxide (VI) concentration. Significant differences ($p<0.05$) in crude protein and Nitrogen Free Extract digestibility were found between the experimental groups and the reference one. The present results indicated the feasibility of using of amaranth flour as plant component in feeding of rainbow trout.

WPŁYW SUPLEMENTACJI MĄKI Z SZARŁATU NA WZROST I STRAWNOŚĆ POZORNĄ PSTRĄGA TĘCZOWEGO *ONCORHYNCHUS MYSKISS*

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S ł o w a k l u c z o w e: *Oncorhynchus mykiss*, *Amaranthus cruentus*, strawność, metoda chromowa.

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Abstrakt

Celem pracy było zastosowanie mąki z szarłatu (*Amaranthus cruentus*) w żywieniu pstrąga tęczowego *Oncorhynchus mykiss*. Przygotowano dwie eksperymentalne pasze z dodatkiem mąki z amarantusa na poziomie (5 i 10%) i jako referencyjną zastosowano paszę komercyjną o podobnej zawartości składników pokarmowych. Badania przeprowadzono na rybach o średniej masie 524,8 ± 28,5 g i długości 35,2 ± 0,6 cm. Doświadczenie trwało 21 dni, podczas których ryby karmiono paszą w dawkach 0,5–1,7% całkowitej biomasy wyliczanej przez hodowlany program komputerowy. Na potrzeby określenia strawności pozornej przygotowanych pasz wykonano walidację metody chromowej dla koncentracji tlenku chromu (VI), otrzymując krzywą korelacji o wzorze $Y = 0.0142X + 0.075$. Różnice istotne statystyczne (p<0,05) zaobserwowano w strawności białka surowego i bezazotowych związków wyciągowych w grupach eksperymentalnych w stosunku do grupy referencyjnej. Uzyskane wyniki wskazują na możliwość zastosowania mąki z szarłatu w żywieniu pstrąga tęczowego.

Introduction

Annual worldwide production of rainbow trout reached more than 800 thousand at tones in 2014 (FAO 2016). Commercial fish farms use extruded fishmeal-based feeds in general (NAYLOR et al. 2000). The percentage of farms using commercial feeds varies from 100% for salmon and 83% for trout. Many aquaculture feed formulations still include fishmeal at levels in excess of 50% (GLENCROSS et al. 2007). Main source of fishmeal comes from marine ecosystems (DEUTSCH et al. 2007). Demand for fishmeal was increasing with the increase development of the aquaculture sector, despite the limited and already overfished marine ecosystems. The replacement of fishmeal as the major protein source with plant origin components is challenging the sustainability of aquaculture industry (VILHELMSSON et al. 2004). Many researchers in recent years tested vegetable: especially soya (KAUSHIK et al. 1995), rapeseed (BUREL et al. 2000), lupine (GOMES et al. 1995), faba bean (OURAJI et al. 2013), pea (THIESSEN et al. 2003), proteins as alternatives for fishmeal.

Amaranth (*Amaranthus cruentus*) grains contain about 15% of protein, and balanced amino acid profile with high level of lysine makes it attractive protein source (PEDERSEN et al. 1987). Main problem with plant components is anti-nutritional factors impact on performance of salmonid fish, with decreased digestion and reduced utilization of proteins followed by decreased growth rates (KROGDAHL et al. 1994). Chemical analysis of amaranth meal showed low level of anti-nutritional factors: saponins and phytic acid (ESCUDERO et al. 2004). VIRK and SAXENA (2003) used amaranth (seeds) in fish diet for *Labeo rohita*. POCZYCZYŃSKI et al. (2014) used amaranth oil as substitution of fish oil in experimental feed for rainbow trout.

The aim of the study was the assessment of use of amaranth meal digestibility crude component in fish feed for rainbow trout *Oncorhynchus mykiss*.

Materials and methods

Fish, feeding, experimental system

Rainbow trout with initial mean body weight of 524.8 ± 28.5 g and mean total length of 35.2 ± 0.6 cm were used in the experiment. Fish (n = 144) were randomly distributed in 9 tanks (3 groups in triplicates: control and two experimental) and acclimated for 4 weeks to the experimental conditions. Each tank volume was 500 dm^3 and tanks were a part of a Recirculation Aquaculture System (RAS). Fish were exposed to a natural light regime of approximately 8 LD and 16 DD. Water quality parameters were measured every day (7.00 am) and the mean values were as follow (mean ± SD): dissolved oxygen 7.72 ± 0.52 mg dm^{-3}, temperature 16.58 ± 0.12°C, pH 7.93 ± 0.14, total ammonia < 0.005 mg dm^{-3}, nitrate < 0.20 mg dm^{-3}, nitrite < 0.001 mg dm^{-3} and phosphates <0.005 mg dm^{-3}.

Every week fish were anaesthetised with propofol (7 mg dm^{-3}) (GOMUŁKA et al. 2014) and each fish was measured and weighted. Feed was offered at 0.5–1.71% of fish biomass of respective group. Feed rations were calculated with Djurnal 1.0 software (Denmark) depending on, biomass, feed gross energy content, water oxygen saturation and temperature. Every week fish were weighted for feed intake (FI) calculated. The experiment lasted 21 days.

Diet preparation

Ingredients and nutrients composition of the experimental diets are showen in Table 1. Fish were fed with two experimental diets containing different levels of amaranth meal (5.0% EF5 and 10.0% EF10) and control feed (CF) – commercial trout pellet AllerAqua Silver (Danemark). Chromic oxide (III) was included in all diet at 1.0% level. Experimental feeds were extruded with a co-rotating twin screw extruder (METALCHEM, Poland) equipped with a Ø 4.5 mm pellet stencil. The entire oil content of the diets was added after the extrusion process. Then, feed remained room temperature until oils were completely absorbed and then keep in refrigerator (6°C).

Chemical analysis

The contents of the basic chemical components in feed and faeces (dry matter, crude: protein, fat and ash) were determined according to standard methods of (AOAC, 2000). Dry matter was determined by drying in an oven at

Table 1

Feeding experiment diets

Ingrediens [%]	EF5	EF10	CF
Fishmeal	44.25	44.25	NA
Wheat flour	20.31	20.31	NA
Soybean meal	15.00	10.00	NA
Amaranth meal	5.00	10.00	NA
Fish oil	6.24	6.24	NA
Soybean oil	6.00	6.00	NA
Vitamin premix*	2.00	2.00	NA
Mineral premix**	0.10	0.10	NA
Choline	0.50	0.50	NA
Ascorbic acid	0.50	0.50	NA
Chromic oxide	1.00	1.00	1.00
Nutrient analysis [%]			
Dry matter	94.27	95.02	93.51
Crude protein	41.01	40.62	42.26
Crude fat	11.95	13.45	13.70
Crude ash	10.44	10.43	8.52
Crude fibre	3.27	3.25	3.22
Chromic oxide	1.00	1.00	1.00
Gross energy (MJ kg^{-1})	18.04	15.41	17.42

NA – data not available

* Vitamin premix (IU kg^{-1} or mg kg^{-1} dry diet): witamin A – 15 000 UI kg^{-1}; witamin D – 6 000 UI kg^{-1}; witamin E – 15; witamin C – 70; witamin B_1 – 0.8; witamin B_2 – 3.0; witamin B_6 – 1.50; witamin B_{12} – $8 \cdot 10^{-3}$; witamin K – 1,5; Biotin – 2,5.

** Mineral premix [mg kg^{-1} dry diet]: calcium – $25 \cdot 10^3$; phosphorus – $27 \cdot 10^3$; sodium – $18 \cdot 10^3$; magnesium – $2 \cdot 10^3$; mangan – 720; iron (II) – 400; copper – 127; zinc – 800; Iodine – 23.

105°C for 24 h. Total protein was determined by Kjeldahl's method and crude fat by Soxhlet's method. NFE was calculated as formula: NFE(%) = 100 – (moisture% + protein% + lipid% + ash% + fibre%). Chromic oxide in diets and faeces was analyzed according to the method of FURUKAWA and TSUKAHARA (1966). The validation of this method for luminometer TECAN Infinity M200 Pro was done before the experiment. The linear regression formula $Y = 0.0142X + 0.075$ was determined for chromium oxide (VI) concentration ($R^2 = 0.997$). Validation parameter were as follow: CV = 2.306%, LOD = 2.302, LOQ = 6.904 for the test range 0.395 – 158 g dm^{-3} chromium concentration. Repeatability was 0.7%.

Sample collection

Fish were caught individually and immediately anaesthetized with excessive propofol concentration (20 mg dm^{-3}). Then fish were killed by brain destruction with sharp scissors. All fish were individually weighed and meas-

ured. Then internal organs were removed and faeces sample was obtained by manual stripping of the posterior part of the gut (AUSTRENG 1978). The samples were pooled for each group. Weight of liver was recorded for Heapato-somatic index (HSI) calculation.

Digestibility determination

Dry matter digestibility was calculated as follow (WINDELL et al. 1978):

$$\text{dry matter digestibility (\% DM)} = 100[-[100\ (\%Cr_2O_3 \text{ in feed}/\%\ Cr_2O_3 \text{ in faeces})]]$$

Apparent nutrient (protein, lipid and energy) digestibility was calculated as follow (MAYNARD et al. 1979):

$$\text{apparent nutrient digestibility (\%)} = 100 - [(\%Cr_2O_3 \text{ in feed}/\%Cr_2O3 \text{ in faeces}) \cdot (\%\ \text{nutrient in faeces}/\%\text{nutrient in feed})] \cdot 100$$

Growth measurements

Growth performance was determined as follow:

1. Percent weight gain [%] = [Final body weight [g] – Initial body weight [g]] · 100.
2. Specific growth rate (SGR) = [(ln final weight – ln initial weight)/time (days) · 100].
3. Feed conversion ratio (FCR) = (feed intake/wet weight gain).
4. Fulton Condition Factor (FCF) = (final weight/final total length^{-3}).
5. Hepato-somatic index (HSI) = (liver weight/body weight) · 100.

Statistical analysis

Normality of data distribution was tested by Shapiro-Wilk test and variance homogeneity by Leven's test. When above assumptions were met, differences between means were analysed using ANOVA and *post hoc* Tuckey's test (TT). For the others, Kruskal-Wallis ANOVA and Mann-Whitney U test (UT) were used. Results were analysed with Statistica 10.0 (Statsoft, USA) software at significance level $p \leq 0.05$.

Results

Fish Growth

Growth performance of experimental fish are presented in Table 2. Different between initial and final measurement not statistic significantly for body length and body weight for all experimental groups (ANOVA, $p>0.05$). The highest fish weight gain (above 21%) was revealed in experimental groups. SGR for CF (0.64) was significantly lower ($p<0.05$), than for EF5 and EF10. FCR noted in experimental group EF5 (1.12) and EF10 (1.00) were better than for CF (1.39). HSI recorded in CF (1.31%) was lower than, those in experimental group EF5 (1.96) and EF10 (2.08). Significantly different ($p<0.05$) in FCF was observed between: CF (1.19) and EF5 (1.30).

Table 2
Growth performance and feed efficiency of rainbow trout fed on experimental diets for 21 days. Values are presented as mean ± SD (range)

	CF	EF5	EF10
Initial total lenght [cm fish^{-1}]	35.41^{a} ± 1.87	35.26^{a} ± 2.29	34.84^{a} ± 2.26
Final total lenght [cm fish^{-1}]	37.05^{a} ± 1.97	36.80^{a} ± 2.42	36.70^{a} ± 2.58
Initial weight [g fish^{-1}]	528.94^{a} ± 110.54	533.44^{a} ± 134.75	512.02^{a} ± 124.11
Final weight [g fish^{-1}]	604.71^{a} ± 110.48	648.96^{a} ± 162.21	623.08^{a} ± 165.24
Weight gain [%]	14.33^{a} ± 1.51	21.66^{b} ± 0.14	21.69^{b} ± 0.64
SGR [%/d]	0.64^{a} ± 0.21	0.89^{b} ± 0.03	0.92^{b} ± 0.09
HSI [%]	1.31^{a} ± 0.09	1.96^{b} ± 0.02	2.08^{b} ± 0.10
FCR (1)	1.39^{a} ± 0.07	1.12^{b} ± 0.02	1.00^{b} ± 0.04
FCF [g cm^{-3}]	1.19^{a} ± 0.05	1.30^{b} ± 0.02	1.26^{ab} ± 0.10

Number indexes show columns with significantly different results ($p\leq0.05$).

Digestibility

Apparent digestibility for dry matter, crude protein, crude lipid and NFE in the test ingredients consumed by rainbow trout are summarized in Table 3. For crude protein, digestibility coefficients exceeding 95% were noted for EF5 and EF10 and were higher than those for commercial feed ($p<0.05$). Apparent digestibility of NFE was higher in feeds with amaranth meal, when compared to control groups ($p<0.05$). No different in apparent digestibility of crude lipid was found. Assimilation of ash was significantly higher in EF5 when compared to CF ($p<0.05$).

Table 3

Table 3. Apparent digestibility [%] of nutrient diet fed to rainbow trout. Results are presented as mean ± SD (range)

Nutrient	CF	EF5	EF10
Crude protein	91.84^{a} ± 1.69	95.86^{b} ± 0.49	95.03^{b} ± 0.74
Crude fat	95.20^{a} ± 3.36	91.31^{a} ± 2.65	88.22^{a} ± 4.73
NFE	47.41^{a} ± 2.71	75.49^{b} ± 2.55	78.40^{b} ± 0.47
Crude ash	80.18^{a} ± 3.21	89.67^{b} ± 1.00	85.66^{ab} ± 2.85

Number indexes show columns with significantly different results ($p \leq 0.05$)

Discussion

The present studies proved that amaranth meal is promising component of feeds for rainbow trout. Amaranth meal addition resulted in better growth indices; higher weight gain, SGR, and Fulton condition factor and lower FCR. However, increased HSI suggest possible negative influence on fish metabolism. This can result from different reasons: excessive energy load; anti-nutritional factors, incorrect balanced feed composition or nutritional deficiency.

Higher values of SGR indicate for better assimilation of feed given to fish. SGR found in the experimental fish (0.89–0.92) was lower than those for soya meal (1.09) and pea protein concentrate (1.21–1.23) reported by ØVERLAND et al. (2009) and noted by REFTSIE et al. (1997) for soy protein concentrate (1.49) and pea meal (1.3–1.6) pea meal concentrate (1.2–1.3) reported by COLLINS et al. (2012) and noted by BORQUEZ et al. (2011) of lupine flour (1.00–1.02) at 10–20% for rainbow trout. Similar SGR in the EF5 results (0.96) was noted by ØVERLAND et al. (2009) of soybean flour at 20% (0.995). However, in all cited above experiments, authors used smaller fish (between 33.5 and 160 g of weight) when compared to fish used in our experiment (initial body wet weight 524.8 ± 28.5g). According to STOREBAKKEN and AUSTRENG (1987) and SGR decreases with increasing fish size.

Many study showed that intensive feeding of fish can result in harmful load of liver in a short time period. HSI in the experimental groups was significantly higher than reported by ESCAFFERE et al. (2007), ØVERLAND et al. (2009) and BORQUEZ et al. (2011) for soya beans concentrate (1.30), soybean flour (1.18) and for lupine flour (1.10) respectively. However, KAUSHIK et al. (1995) reported values similar to our results for rainbow trout fed with feeds based on fishmeal (2.0) and casein (2.3).

Enlargement of liver size and glycogen concentration was increased with elevated levels of dietary carbohydrate in several fish (TIEN et al. 2012) present in amaranth meal (above 40%). Absorbed carbohydrate that is not used for

energy usually accumulated in the liver of fish both as lipid and as glycogen after being converted (BRAUGE 1994). Moreover, the effect of fat deposition in the liver resulting from carbohydrates in the lipogenesis process and source of oil (fatty acid profile) used in fish diet. HSI increased due to accumulation of fat in the liver was observed in fish fed with feeds contains on vegetable oil (OLSEN et al. 2000). CABALLERO et al. (2002) reported that some fatty acid (predominantly C16:0) tend to accumulate in rainbow trout liver. Amaranth oil contains 19.46% of C16:0 fatty acid (POCZYCZYŃSKI et al. 2014). High content of C16:0 acid can be one of possible reasons of high HSI value in experimental fish.

Usually FCF for trout ranges between to 0.80–1.60. The value of FCF is influenced by age and sex of fish, season of the year, stage of maturation, fullness of gut, type of food consumed, amount of fat reserve, degree of muscular development (BARNHAM and BAXTER 1998). Pathological changes in body proportions caused by Myxosporea can result in very high value of FCF (1.62–1.88) in some cases (WŁASOW et al. 1997). FCF recorded in our experimental fish (1.26–1.30) was similar to those reported by STOREBAKKEN and AUSTRENG (1987) (1.26–1.64) for rainbow trout fed with 21 days period at 8°C and 12°C. In both cases, experimental feeding period was relatively short.

The increased of HSI can be a result of increased crude protein and NFE digestibility. Digestibility of amaranth crude protein is at a high level exceeding 95%. Similar Apparent digestibility was noted by SUGIURA et al. (2000) of the meal of animal origin (above 95%), and noted by CARTER and HADLER (2000) for soybean (95.31–95.86), lupine (95.65–95.90) and pea meal (95.22–95.48). The bioavailability of protein amaranth was comparable to the results obtained by OURAJLI et al. (2013) of beans (above 95%).

The main reason of low digestibility of NFE is hard to digest starch which is the main complex carbohydrate in vegetables seeds. Usually Apparent digestibility of NFE in trout feeds is 50%. Our results show that digestibility of amaranth NFE is much higher (74.5–78.4%). Digestion is thought to be the primary limiting step in the utilization of starch for growth (NRC 2011). The majority of commercially available starches have a medium (10 to 25 μm) or large (>25 μm) granule size, while amaranth seed is one of the few sources of small-granule starch, typically 1 to 3 μm in diameter, and having regular granule size (HOSENEY 1994). Amaranth seeds contain fine particle starch which easy to assimilate. In many fish species, including trout, increased availability of dietary carbohydrates can result in liver disturbances (WALTON 1986).

The relationship between digestibility of protein, fat and NFE were reported by GRISDALE-HELLAND and HELLAND (1997) for different levels of fat and carbohydrates in fish feed. They found that decrease of fat and starch level in feed resulted in increased protein digestibility. Our results suggest other

trend, protein digestibility was higher in fish offered with feed of higher NFE digestibility. At the same time digestibility of fat was decreased. Explanation of this phenomenon needs further research.

Apparent digestibility of fat in experimental groups was markedly lower than control (Table 3). It was shown that amaranth oil contain more than 23% of saturated fatty acids mainly C16:0, C18:0; C20:0 (ESCUDERO et al. 2004). CABALLERO et al. (2002) proved that digestibility of saturated fatty acids in rainbow trout is between 38 and 71% for stearic acid (C18:0) and 61 to 92% for palmitic acid (C16:0). High share of relatively hard to digest fatty acids in experimental feeds could results in worse digestibility of crude fat.

Conclusions

The present study demonstrated the usefulness of amaranth meal as a component of commercial feeds for rainbow trout. The experiment revealed that 5% replacement of soybean meal with amaranth meal in feed improves growth of trout. However, higher level of amaranth meal induced negative influence on the growth performance and liver condition. Phenomena of higher digestibility of NFE accompanying with higher digestibility of protein and lower digestibility of fat needs further study.

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FROM RESTORATION TO REVITALIZATION: HOW TO RECOVER RECREATIONAL VALUES OF URBAN LAKES. A CASE STUDY OF LAKE DOMOWE DUŻE IN SZCZYTNO

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K e y w o r d s: lake, restoration, recreation, land management for tourism, water quality.

A b s t r a c t

Lake Domowe Duże (surface area 54 ha, maximum depth 7.2 m) is one of the two lakes lying in the town limits of Szczytno. For years, despite its large recreational potential, the lake had been rarely exploited by town residents or visitors due to its classless water quality. The restoration project initiated in 2010 has raised interest in spending leisure time on this lake. The natural conditions affecting the lake's waterfront have been analyzed, as well as the impact of the lake's morphometric properties and the land management along the shoreline on a possible use of the lake for recreation, including angling.

The results suggest that owing to its large size and morphometric diversity, as well as the recently developed infrastructure for the tourism industry, Lake Domowe Duże can serve various forms of recreation. The improvement of the lake's water quality achieved in recent years has created opportunities for water recreational activities and enhanced the angling quality of this water body.

OD REKULTYWACJI DO REWITALIZACJI – PRZYWRACANIE WALORÓW REKREACYJNYCH AKWENOM MIEJSKIM NA PRZYKŁADZIE JEZIORA DOMOWEGO DUŻEGO W SZCZYTNIE

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Abstrakt

Jezioro Domowe Duże (powierzchnia 54 ha, głębokość maksymalna 7,2 m) jest jednym z dwóch akwenów miejskich Szczytna. Mimo znacznego potencjału do rekreacyjnego wykorzystania, zbiornik ten, z uwagi na pozaklasową jakość wód, w niewielkim stopniu służył mieszkańcom i turystom. Zainicjowana w 2010 r. rekultywacja jeziora spowodowała wzrost zainteresowania aktywnym wypoczynkiem nad badanym akwenem.

W pracy przeanalizowano istniejące uwarunkowania przyrodnicze kształtowania przestrzeni przywodnej jeziora oraz wpływ cech morfometrycznych zbiornika i sposobu zagospodarowania linii brzegowej na możliwość wykorzystania rekreacyjnego, w tym do uprawiania wędkarstwa.

Uzyskane wyniki wskazują, że dzięki swej wielkości i zróżnicowaniu morfometrycznemu, a także powstaniu nowych elementów infrastrukturalnych, bazy turystycznej, Jezioro Domowe Duże może być wykorzystywane do różnorodnych form rekreacji. Uzyskana w ostatnich latach poprawa jakości wody stwarza dogodne warunki do rekreacji nawodnej, jak również pozytywnie wpływa na atrakcyjność wędkarską akwenu.

Introduction

Among all landscape features, lakes are undeniably among the greatest nature treasure. Lakes also enhance the recreational value of lake districts. However, they are extremely vulnerable landscape elements, sensitive to anthropopressure and ecological degradation (KAJAK 2001, DUNALSKA et al. 2015). Clean lakes are an excellent base for development of tourism. Conversely, eutrophic and hypertrophic lakes can repel recreation seekers, and water pollution can pose a threat to the health and even life of swimmers. This hazard can be viewed as caused by chemical pollutants, resulting from water contamination, or by substances released into the water environment due to hypertrophy, i.e. overfertilization of a given ecosystem. The latter include organic and inorganic decomposition products, such as methane, hydrogen sulfide and other volatile compounds, e.g. responsible for noxious smell, and toxins released by decomposing cells of algae and blue-green algae (KAJAK 2001).

Eutrophication of lakes is a natural development. It occurs in every landlocked water body, surrounded by a catchment basin which feeds it with water and organic matter. If the natural conditions are undisturbed, eutrophication is very slow, imperceptible in an average person's lifespan. However, anthropogenic transformations of the environs of lakes which have been taking place over the past few decades have enlarged the influx of contaminants to lake waters, which rapidly accelerates their ageing (KAJAK 2001). Urban lakes are in a specific situation (BIRCH and MCCASKIE 1999, TANDYRAK et al. 2015). Against the backdrop of omnipresent industrialization and urbanization, lakes are perceived as a refuge and are willingly chosen as sites for regaining physical and mental well-being (HALL and HARKONEN 2006).

Consequently, they are also seen as a leverage for the growth of tourism and hospitality, which determines their value for the society (FURGAŁA-SELEZNIOW et al. 2012). Meanwhile, they are exposed to a dual risk of degradation: firstly, due to a relatively stronger pressure by recreation seekers, and secondly, because of the increasing development of the lake's catchment, which generates more sewage, wastewater and rainwater, disturbs the water balance, reduces water circulation and adds more technical infrastructure along the lake's shores.

The social pressure to maintain good quality of waters in lakes that serve recreational functions gives rise to efforts to restore water bodies degraded by ill-considered human actions. Nevertheless, due to very intricate biogeochemical relations in water ecosystems, it is difficult to identify correctly the causes of degradation and therefore to work out plans for effective restoration. Hence, restoration projects frequently fail to generate expected benefits, and promotion of certain recreational functions of a given lake can even harm its water ecosystems. A need is felt to elaborate algorithms supporting lake restoration plans which would account for unique natural features and the specific character of each lake.

Our objective has been to present the assumptions and effects of a restoration plan prepared for a typical urban lake, such as Lake Domowe Duże in Szczytno, and discuss it from the perspective of their contribution to improved tourist and recreational values of this water body.

Material and Method

Research object

Lake Domowe Duże is the largest water body in the urban agglomeration of Szczytno. Together with Lake Domowe Małe (Figure 1), it composes a water complex, which adds more appeal to the town center. The catchment (the urban and rural type) covers an area of about 4.3 km^2. The northern and eastern shores, within the town limits, are flanked by the buildings in Bartna Strona Street. To the east, where the lake stretches out to some green areas, there is a municipal beach, a pier and the Interschool Sports Centre with a water equipment rental. The southern shores are occupied by some greeneries, garden allotments and farmland. The south-western end of the lake borders with the village Korpele while to the north the lake reaches a small locality called Kamionek.

For many years, Lake Domowe Duże had served as a sink for municipal sewage and wastewater, industrial wastewater and cooling waters from indus-

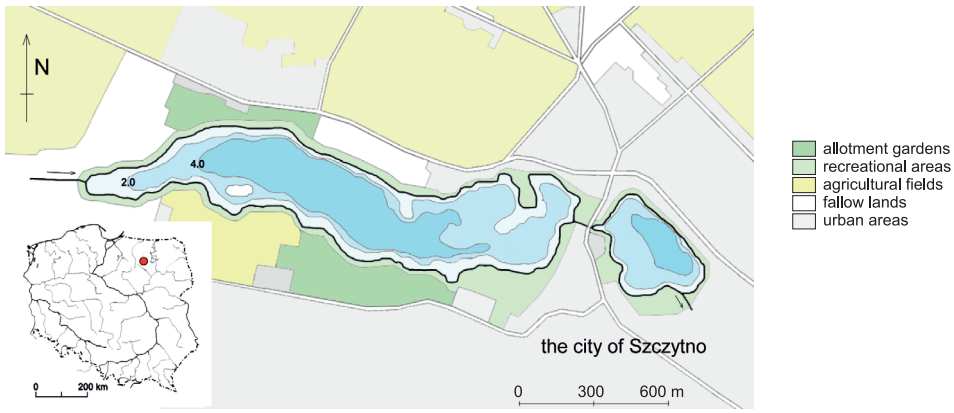

Fig. 1. Location and surroundings of Lake Domowe Duże in Szczytno

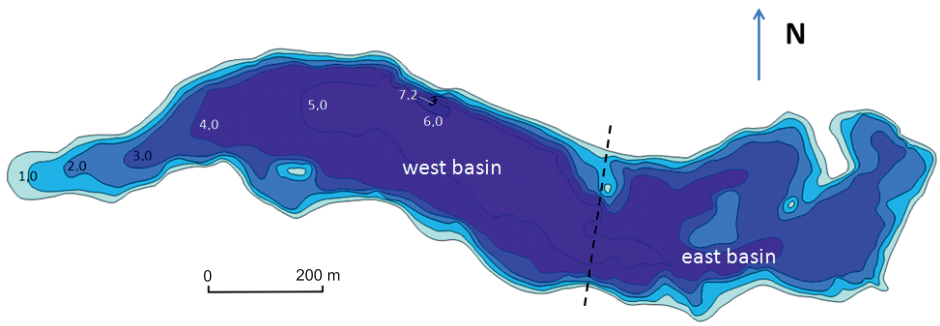

Fig. 2. Morphometric features of Lake Domowe Duże

trial plants situated in this part of Szczytno. The recent modernization of the urban sewage system has evidently limited the degree of degradation of the lake waters. Currently, there are no sources of point pollution to the lake, although the rainwater drainage system still poses a threat to the lake. The risk is compounded by the fact Lake Domowe Duże is extremely vulnerable to degradation (ŁOPATA et al. 2013) due to its low depth (Figure 2), high water mixing intensity, diverse shoreline and the type of land management in the catchment that promotes man-made pressure. With these characteristics, the lake was unable to regain a good ecological status even after the discontinuation of sewage and wastewater discharge. Another reason why the lake ecosystem could not function well was the decrease in the water table level (by over 1 m) and surface area (Table 1) due to excessive drawing of water for industrial purposes. The town council, responding to the local community's worries over the poor quality of water in Lake Domowe Duże, decided to

initiate its restoration (DUNALSKA et al. 2014), eventually carried out in 2010–2012, by the University of Warmia and Mazury in Olsztyn. Basic parameters of the shape and size of Lake Domowe Duże, according to historical sources and present, detailed measurements are presented below.

Table 1
Basic morphometric data of Lake Domowe Duże in Szczytno, according to archival and contemporary sources

Parameter	Unit	IFI 1964	UWM 2012
Area	ha	62.1	58.7
Maximum depth	m	5.4	7.2
Mean depth	m	2.8	3.45
Elongation	–	5.86	5.95
Shoreline: length	m	5300	5074
Development index	–	1.90	1.87
Fishing economic indicator	m/ha	85.3	84.6

IFI – Inland Fisheries Institute in Olsztyn
UWM – University of Warmia and Mazury in Olsztyn

Methodology

The lake's morphometric characteristics were analyzed based of archived data: the bathymetric plan and morphometric chart made by the Inland Fisheries Institute (1964, sampling density 244 points/100 ha) and more contemporary modelling produced in 2012 by the Department of Water Protection Engineering in the UWM in Olsztyn (1357 measurement points per 100 ha).

Field observations and measurements, which help to identify the accessibility of the lake's shores for tourist purposes, transformation within the waterfront zone and the lake's water quality, were done in 2004–2006 and 2010–2015 (water chemistry and hydrobiological parameters on average 4–5 times during the plant growing season), as part of the lake's monitoring conducted by the Department of Water Protection Engineering.

The assessment of the lake's recreational usefulness adhered to the guidelines of DEJA (2001). The analysis included the qualitative and quantitative valuation of the limnometric characteristics of the lake (surface area, average depth, shoreline development and elongation), the ecological condition (the shores and open waters being overgrown with emergent plants) and of the catchment (the share of forested land in the immediate surroundings of the lake).

Our analysis of the recreational suitability of the lake for angling was accomplished according to the methodology proposed by SKRZYPCZAK (2005). This evaluation included a comparative assessment of the lake's six attributes that identify if the lake's shores can reached. They fall into characteristics which make the lake more attractive for anglers (stimulants) or limiting the appeal (destimulants). The indicators were assigned weights which reflect the varied effects of given attributes on the potential use of the lake as a fishing destination. The final stage in the calculation was to derive synthetic measures of the lake's attractiveness, in a range of 0.000 to 1.000.

Research Results and Discussion

Natural conditions and the recreational usefulness of the lake

The natural attributes of Lake Domowe Duże make it a poor choice for recreational activities. In line with the broadly accepted methodology for evaluating recreational values of lakes (DEJA 2001), Lake Domowe Duże belongs to class IV, which is the category of the least attractive lakes (Table 2,

Table 2
The results of grading Lake Domowe Duże on the background of the score of features determining the suitability of water bodies for recreation

Parameter							Points
Area [ha]	mean depth [m]	shore development index	elongation index	overgrowing of the shoreline [%]	overgrowing of water surface with submerged vegetation [%]	afforestation of coastal zone [%]	
–	0.0–2.0	–	–	> **50**	> 50	no forests	0
≤ 50	**2.1–5.0**	1.00–1.50	1.0–1.4 >7	–	–	≤ **20** **80.1–100.0**	1
50.1– **–100.0**	5.1–15.0	**1.51–2.00**	**1.5–3.0** **5.1–7.0**	25.1–50.0	**10–50**	–	2
100.1–150	15.1– –30.0	2.01–2.51	3.1–5.0	–	–	20.1–40.0 60.1–80.0	3
150.1–300	–	2.51–3.00	–	≤ 25	<10	–	4
> 300	–	>3.01	–	–	–	40.1–60.0	5
Lake Domowe Duże in Szczytno (feature value/points):							
58.7/2	3.45/1	1.87/2	5.95/2	95.7/0	12.5/2	7.7/1	total points 10 (IV class)

Bold type – the range of values proper for the investigated lake.

Table 3). It is worth noticing, however, that the classification score (10 points) is close to the thresholds for moderately attractive lakes, and therefore it would be a far-fetched opinion that the shape of the lake's bowl or the qualities of its surroundings disqualify this lake from any recreational use. In particular, the limited plant cover of the water table (12.5%) and the diverse share of the lake's bowl together with the relatively large surface area (> 50 ha) make up the lake's potential ability to serve recreational purposes. Conversely, from the point of view of recreation seekers the lake's most undesirable feature is the very poor access to the shores (just 5% of the shoreline is free from reeds). Practically, the municipal beach located at the easternmost end of the lake is the only site suitable for sunbathing with free access to the water.

Table 3

Classes of the lakes recreational attractive (according to Deja 2001)

Lakes attractive	Class	Points
Very attractive	I	21.80–29.00
Attractive	II	16.00–21.75
Moderately attractive	III	10.20–15.95
Poorly attractive	IV	to 10.15

We also reviewed the conditions for angling in this lake. The fishery management authority responsible for the lake is the Polish Angling Association, Olsztyn Branch. Angling is allowed provided an angler has a required permit and paid a due fee to the lake's fishery management authority. There are no other fishing limits imposed or licenses required, which means there are no other formal constraints onangling. The angling value of a lake depends on the species structure in fishing grounds (CZARKOWSKI et al. 2012). In this regard, Lake Domowe Duże has much to offer – there are such fish species as carp, tench, bream, white bream, roach, rudd, grass carp, crucian and German carp, as well as predatory fish like pikeperch, perch, pike and eel. In recent years, the lake has been heavily stocked with predatory fish fry and fingerlings (data from the Polish Angling Association in Olsztyn, accessed online).

Table 4 summarizes our assessment of the lake's recreational quality for angling, completed according to SKRZYPCZAK (2005). The results suggest that the lake is moderately suitable for angling. In this regard, again, the broad belt of emergent plants growing along the shoreline proved to be a limiting factor.

Table 4

Assessment the recreational suitability of Lake Domowe Duże for fishing (according to SKRZYPCZAK 2005)

Feature	Unit	Character of property*	Weight	Value	
				west basin (33.4 ha)	east basin (25.3 ha)
Shoreline development index	value of factor	*S*	0.10	1.54	1.45
Shoreline with a 1-5 m wide belt of emergent plants	% of shoreline length	*S*	0.25	11.7	17.0
Shoreline with a > 5 m wide belt of emergent plants	% of shoreline length	*D*	0.10	87.6	74.1
Drainage basin (up to 100 m) afforested, with thegroundwater level < 1.0 m	% of shoreline length	*S*	0.20	0,0	15.5
Drainage basin (up to 100 m) covered with boggy forests, wetlands and swamps	% of shoreline length	*D*	0.10	9.4/0.0**	0.0
Access to the water	points/100 m shoreline	*S*	0.25	2.05	3.02
The value of synthetic gauge				0.441	0.894

* *S* – stimulating nature (stymulants), *D* – limiting nature (destymulants);
** – 0.0 appointed because of the presence of a new foot/bicycle path around the lake.

At the same time, the above analysis revealed distinctly different qualities of the lake's two basins. In the light of the adopted methodology, the eastern basin appeared to be superior, with its better access to water (68 access points in total), more diverse phytolittoral (30% higher share of the shoreline only slightly overgrown with helophytes) and more attractive environs of the fishing grounds owing to the presence of tall plants. However, the fishing quality of a lake also depends on the shape of the bottom (KRUPA et al. 2007). The eastern basin has numerous shallow areas and underwater hillocks, which favour the catch of certain fish species (pike, perch, tench), while the western part of the lake, with slightly diversified relief of the bottom and a much deeper average depth (3.8 m versus 3.05 m for the eastern basin) can be preferred by pikeperch and bream. In brief, anglers' preferences will largely depend on their fishing technique and expected catch of specific fish species.

Restoration of the lake

The restoration of the lake was accomplished with a phosphorus inactivation approach. Nowadays, this is one of the most effective methods available for improvement of water quality (ŁOPATA and GAWROŃSKA 2006, ŁOPATA

2013, GROCHOWSKA et al. 2013). In essence, amounts of phosphorus in water are precipitated into insoluble compounds with special preparations. Second to nitrogen, phosphorus is the major nutrient in water that stimulates the growth of water plants, thus the proliferation of phytoplankton decreases when excess phosphorus is removed from water depths. This is a highly effective method, with results lasting for over a decade (GROCHOWSKA et al. 2013).

In order to inactivate phosphorus in Lake Domowe Duże, the poly-aluminum chloride was used. This is a new generation coagulant with highly effective binding properties. During its application to the water, Al ions hydrolyze into hydroxides forms with high affinity to phosphorus. These particles aggregate and settle down towards the bottom sediments as amorphous flocs. As it was expected, there was a rapid reduction of the number of plankton algae and subsequent improvement in the water transparency caused directly by the limited phosphorus level in the water of Lake Domowe Duże. Average algae biomass has decreased about two times (to the value about 10 mg l^{-1}), the phosphorus content decreased below 0.1 mg l^{-1}, (about 2.5 times, comparing to concentration occurring before restoration) and the water transparency has reached a level clearly above 1 m – which is the desired value for bathing (Figure 3). As a result of this improvement of water quality, a nuisance algal blooms have been removed. This outcome, having a measurable impact on the recreational value of the lake, served as a fundamental argument for the re-establishment of a municipal bathing beach on the lake. It is worth noticing that the upper threshold of water transparency, sufficient to allow the use of waters for swimming, was achieved already in the first of the three implementation stages of the phosphorus inactivation technology.

Another manifestation of the improvement of water transparency for recreational purposes was the re-establishment of submerged plants, stimulated by a better access of light to deeper layers of water (ŁOPATA et al. 2013). The presence of submerged plants has a direct influence on the stabilization of chemical conditions within the lake waters. These plant assemblages also play numerous roles in the ecosystem: they are arefuge for valuable zooplankton as well as a breeding and foraging site for many precious fish species; moreover, they prevent the motion of bottomsediments induced by strong waves (KAJAK 2001), including the ones caused by recreational activities, for example motor water sports. A higher biodiversity of the water body is no less important as it enhances the nature-related value of the whole water ecosystem.

It should be emphasized that the restoration works had been planned so as to ensure that their impact, in respect of scheduling, execution and assurance of ecological security, would meet the expectations of the lake's fishery manager, i.e. the Polish Angling Association. Simultaneously, the project team had adopted the concept proposed by many researchers (CZARKOWSKI et al. 2012, JEPPESEN et al. 2012), suggesting that proper fishery management

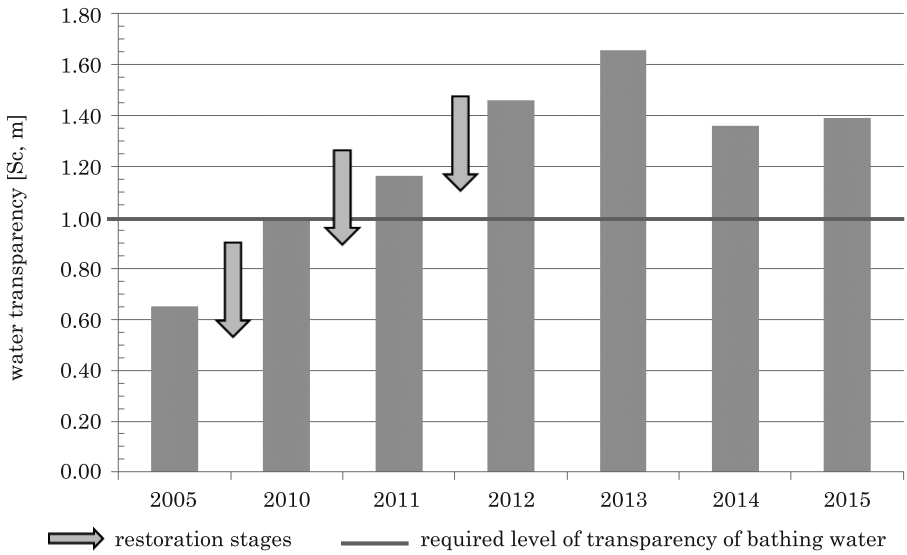

Fig. 3. Changes of water transparency in Lake Domowe Duże in recent years

could be a very efficient tool in sustaining the effects of technical lake restoration works. The stocking of fish species should be planned so as to reduce the risk of fish disturbing the bottom sediments. This is why the lake was not stocked with carp and other species which can contribute to the resuspension of bottom sediments, and therefore induce secondary water pollution. Meanwhile, the fry and fingerlings of predatory species, that is pike and pikeperch, were stocked more intensively (on average 25 thousand specimens a year). These efforts can be classified as implementation of biological restoration methods, known as fishery biomanipulation. As a consequence, the trophic cascade effect is amplified, which means that the number of zooplankton-foraging fish species decreases to the advantage of predatory species, and that creates more favourable conditions for plankton crustaceans, which control populations of plankton algae, including the most unwanted green-algae species.

Revitalization of the near-water space

To release the recreational potential of the lake, it was essential during the restoration works to improve the water quality up to a standard when recreational use of this water body would again be possible (twenty years after bathing had been prohibited). At present, the municipal bathing beach has been thoroughly refurbished and equipped in line with the current norms as

well as the formal and legal regulations in force. The bathing season runs from 15 June to 15 September, and the beach is visited by an average of 30 to 40 people a day. To protect the lake from excessive anthropopressure, it was very important to install toilets serving the municipal beach. Now, there are two toilets available for the public in the Sports and Recreation Centre and one, opened seasonally, on the beach.

The success of the restoration works was a driving force behind the subsequent efforts undertaken to make the lake more appealing to visitors. Having recognized the need to strengthen the town's tourist potential, such actions as further development of tourist and recreational infrastructure around Lake Domowe Duże have been included in the spatial planning and economic development strategy for Szczytno. The following have been distinguished as having the highest value: the foot and bicycle path around the lake, and an active leisure park situated at the southernmost environs of the lake. Once these investments were completed, the total area under recreational use around the lake was enlarged by 10 ha. Street lights and benches were installed along the foot and bicycle path, which encourages all families, including elderly persons and children, to take advantage of this facility. Noteworthy, the construction of the path in no way collided with the goals and forms of the lake's ecosystem natural protection. The bicycle path runs on a former walking path, it has mineral surface, permeable to rainwater, is not elevated above the ground level in a way that could interfere with the surface runoff from the catchment and does not obstruct a stream that feeds to the lake (road culvert). Consequently, the cycling and walking path does not change the lake's water relations nor does it deteriorate the soil retention capacity in the lake's surroundings.

Another benefit stemming from the completed restoration project around Lake Domowe Duże is the increasing interest of town residents in the offer of the sports center and water equipment rental, which became richer to meet the growing demand. The social dimension of this development cannot be neglected because it equates promotion of physical fitness, especially among young people.

The landscape values and aesthetic quality of the lake's surroundings have also been affected by the street architecture objects, created parallel to the restoration works, for example paths, benches, terraces, flower beds with ornamental plants, which decorate the park off the eastern shores of the lake. They make a perfect contribution to the town's recreational area and, together with the mentioned infrastructure components, create a new quality of the municipal landscape, which encourages both residents and visitors to indulge in outdoor pastime activities.

Conclusion

The case of Lake Domowe Duże in Szczytno proves that urban lakes, even less attractive in regard of a possible recreational use, can play an important role in the life of local communities. They can be used by residents, but they can also serve as some leverage for the growth of tourism in a given area. Commonly, a barrier to exploiting the full recreational capacity of such water bodies is the unsatisfactory quality of water, which precludes polluted lakes from serving certain forms of tourism and recreation, mostly swimming or water sports. The studies and observations presented in this report indicate that when self-purification of a water body is impossible, even after sources of pollution have been cut off, an adequately designed restoration technological solution should be implemented to restore good water quality. For Lake Domowe Duże, it was a relatively quick and simple method, whose essence was to decrease the pool of substances nourishing the lake, such as phosphorus, by inactivation. This method is becoming an increasingly popular tool to improve degraded water bodies. However, like in any other case, a technical approach should be supported with biological methods, which would take into account unique ecological conditions of a given water body. In the case of Lake Domowe Duże, the fishery management, and especially the new fish stocking policy, implemented as a contribution of one of the lake restoration team members, turned into an additional instrument that helped to achieve the stability of water quality originally improved with the technical method.

The efforts undertaken to re-create the natural and recreational values of Lake Domowe Duże in Szczytno and its surroundings are a yet rare example of holistic projects designed to revitalize waterfronts. It should be highlighted that the satisfying outcome of this project was possible owing to the cooperation of several participants – the local government, which bears responsibility for the area occupied by the lake and its environs, the fishery management authority and the research unit. The case study discussed herein proves the importance of synergistic relationships and their activation in such projects, when the collaboration of individual subjects generates a total effect that surpasses the sum of individual effects achieved by each subject alone.

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