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Physicochemical properties of achenes of buckwheat cultivars affecting the development of grain weevil (*Sitophilus granarius* L.) and lesser grain borer (*Rhyzopertha dominica* F.)

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Abstract

The development of two storage pests, grain weevil (*Sitophilus granarius* L.) and lesser grain borer (*Rhyzopertha dominica* F.), was studied on achenes of buckwheat representing two species: common buckwheat ('Red Corolla', 'Karmen' and 'La Harpe') and tartary buckwheat (Olsztyn, Lublin and Chinese accessions). The analysis included most important physical characteristics (thousand seed weight, husk content and thickness), and basic chemical composition of buckwheat seeds and husks (crude ash, crude fibre, total protein and total flavonoids). Based on the assessment of the development parameters of *R. dominica* and *S. granarius*, an attempt was made to determine which physicochemical characteristics of buckwheat achenes affected the development of these beetles. The results suggest that buckwheat achenes are a habitat in which both species of beetles can develop albeit at different dynamics. *R. dominica* found suitable conditions for the development on tartary buckwheat achenes, whereas achenes of common buckwheat proved to be a less favourable habitat. With respect to *S. granarius*, only single individuals completed their development on achenes of both buckwheat species, which indicates that this food source is a rather unattractive habitat for the lesser grain borer. The physical factor which deterred *S. granarius* from settling on buckwheat is most probably the thick husk of achenes. However, this feature is not a barrier to the lesser grain borer, and the properties which can contribute to the toughness of food (i.e. the per cent share of husk in the whole achene, husk thickness and content of crude fibre) can be decisive factors in beetles accepting or not a given buckwheat accession. Other traits which significantly affected the development of this pest included higher concentrations of total protein and total flavonoids in seeds.

Key words: physicochemical properties of achenes of buckwheat, storage pests.

Introduction

Buckwheat has been an agricultural crop for thousands of years (Ohnishi, 1998). Over the last decade, the global production of buckwheat has stabilized on an average level of nearly 2.1 million tons. The main producers of this pseudocereal are China and Russia, whose combined average production output makes up almost 66% of the world's yields. Five largest buckwheat producers include also Ukraine, France and Poland. The highest buckwheat yields were obtained in 1992 – nearly 5 million tons, to which China made a contribution, equal 62%. Since then, the global production of this pseudocereal has nearly halved and China's production decreased almost fourfold, to about 740,000 tons. In 2014, 244,400 tons of buckwheat were harvested in the European Union, and the statistics of the last decade show a growing trend in the production of this species in Europe (FAOSTAT, 2016). Among over twenty buckwheat species only two, i.e. common buckwheat (*Fagopyrum esculentum* Moench) and tartary buckwheat (*F. tataricum* Gaertn.), have commercial value (Zhou et al., 2012; Cho et al., 2015). Buckwheat produces pyramid-shaped achenes, which, depending on geographical regions, are processed into groats or flour. Buckwheat products are distinguished by valuable nutritional, dietary and pro-health qualities (Ahmed et al., 2014; Jing et al., 2016). They do not contain gluten, and are a rich source of all essential amino acids, high quantities of fibre and minerals (Wijngaard, Arendt, 2006). Buckwheat achenes contain large amounts of flavonoids, e.g., rutine, that is compounds characterized by high antioxidant activity (Zielińska et al., 2012 a; b). All these characteristics of buckwheat achenes contribute to their increasing popularity in the recent years as raw material for production of functional food (Zhang et al., 2012).

Buckwheat achenes stored in warehouses can become a potential source of food for many storage insect

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pests. The extent to which they are infested and the type of a foraging pest depend primarily on the degree to which achenes are fragmented and on the presence or absence of husks on achenes. Husked, crushed, milled or thermally processed achenes are a good source of food to flour mite (*Acarus siro* L.), khapra beetle (*Trogoderma granarium* Everts), Mediterranean flour moth (*Ephestia kuehniella* Zeller), Indian meal moth (*Plodia interpunctella* Hubner), rice moth (*Corcyra cephalonica* Stainton) and confused flour beetle (*Tribolium confusum* Duv.) (Locatelli, Limonta, 1998; Ciepielewska et al., 2000; Kordan, Gabryś, 2013). The husk covering an achene acts as a kind of barrier which prevents the foraging of secondary pests and can significantly inhibit the foraging by primary grain pests (Zadernowski et al., 1992; Ciepielewska, Fornal, 2004). The latter include mainly the lesser grain borer (*Rhyzopertha dominica* F.) and grain weevil (*Sitophilus granarius* L.), that is two species which belong to the most dangerous pests of stored grain in the moderate climate zone (Edde, 2012). These species (adults and larvae) can feed on buckwheat achenes and may pose a threat to them during storage. Infestation by *S. granarius* and *R. dominica* causes biomass loss and worse quality of achenes (Delobel, Grenier, 1993; Ciepielewska, Fornal, 2004; Mason, McDonough, 2012). Apart from the physical characteristics of buckwheat achene husks, which can deter grain-foraging pests, another important factor in this regard is the presence of polyphenols which belong to the classes of flavonols and tannins (Luthar, 1992). It has been proven that these compounds can be considered as component factors which could play a decisive role in shaping the plant's resistance to the foraging by phytophagous fauna, and their effect can be antifeedant, toxic or inhibiting digestive processes (Wrubel, Bernays, 1990; Torres et al., 2003; Barbehenn et al., 2005).

S. granarius and *R. dominica* are species of beetles which are classified among primary grain pests, able to make damage to whole kernels. There are certain differences between these species in how they settle on grain, including oviposition and food ingestion by larvae. Females of grain weevil bite a small hole in a kernel, into which they deposit an egg. Next, they seal the hole with the so-called cork that is some viscous substance mixed with the kernel's starch. Females of the lesser grain borer deposit eggs on the surface of grains, and the hatched larvae bore into grains, where their further development takes place. The first larval stages of *R. dominica* can forage on the dust generated by adult individuals, and later they bite into the grain through the lesions made by adults or through natural cracks and other small damage traces on kernels (Gołębiowska, 1969; Edde, 2012). This behaviour pattern most probably enables the lesser grain borer to settle on the food on which grain weevil either develops very poorly or does not develop at all.

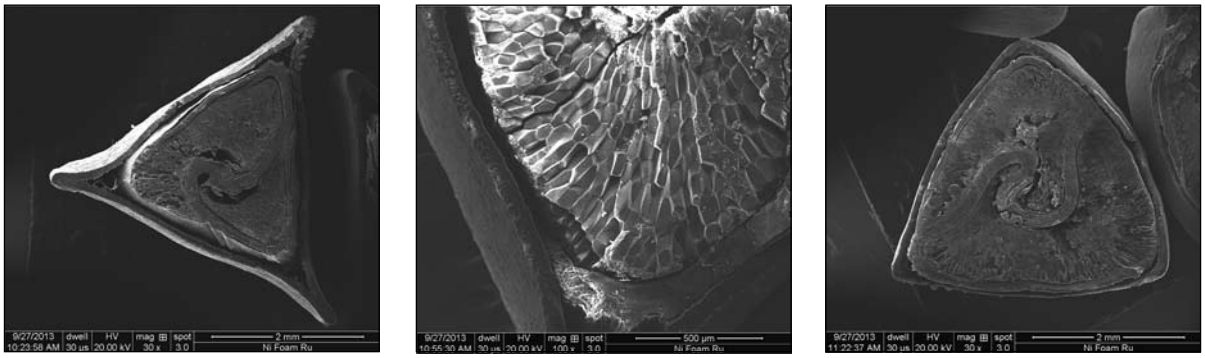
By combining our knowledge about the physical and chemical properties of buckwheat achenes which contribute to their better resistance to the foraging by phytophagous insects, we can obtain some valuable information applicable in the process of breeding and creating new buckwheat cultivars. Therefore the purpose of this study was to identify which physicochemical characteristics of buckwheat achenes can have influence on the development of grain weevil and lesser grain borer.

Materials and methods

Materials. Experiments were carried out at the Department of Entomology, Phytopathology and Molecular Diagnostic of the University of Warmia and Mazury in Olsztyn, Poland in 2015 and 2016 (laboratory tests). In this experiment, the development of two selected species of beetles was studied on achenes of two buckwheat species – common buckwheat (*Fagopyrum esculentum* Moench), the cultivars 'Red Corolla', 'Karmen', 'La Harpe', and tartary buckwheat (*F. tataricum* Gaertn.) (Tartary), two Polish local accessions, one from Olsztyn (Olsztyn accession – OA) and one from Lublin (Lublin accession – LA), and one form selected from Chinese cultivar 'Kuqiao' (Chinese accession – CA). The control treatment contained grain of cultivar 'Muszelka' wheat. The analyzed achenes and control kernels were conditioned in a breeding chamber (Sanyo MLR – 350 H) for 7 days at a temperature which is optimal for a given species of beetles. Afterwards, the material was passed through a sieve with 1 mm mesh net (to remove dust) and then 5-gram samples were weighed out. The samples were placed in PVC-U containers measuring 8 cm in diameter and 3 cm in height. Each container was closed with a top fitted with a ventilation hole measuring 2 cm in diameter and secured with chiffon net to prevent beetles from escaping the containers.

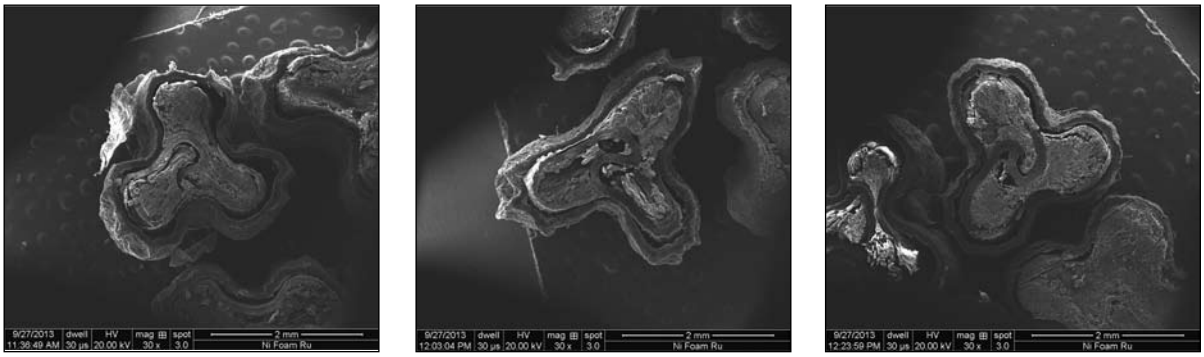
Physicochemical properties of buckwheat achenes. A thousand seed weight (TSW) for achenes was determined according to the ISTA (2013) methodology. To this aim, 8 samples each of 100 achenes were taken randomly and weighed on a laboratory scales WM 118 (MeraMont) at an accuracy of d = 0.005 g. The variability coefficient was calculated for the results and once it was confirmed not to exceed 4% the average weight obtained from the replicates was multiplied by 10. The content of a husk in an achene was determined by the weighting method. For each cultivar, 4 samples each of 250 achenes were taken randomly and weighed. The pericarps were removed from the achenes manually and weighed to calculate their per cent share to the achene's weight. The husk's thickness was measured according to a microphotograph taken under a scanning electron microscope, using software *ImageJ*. For each of the analyzed forms, 10 cross-sections of achenes were made at the middle of their height. The cross-sections were observed under a high-definition scanning electron microscope Quanta 250 FEG (FEI) at 100-fold magnification and photographed. The thickness of the husk was measured for each object, at three sites in the middle part of the pericarp of an achene. The content of crude fibre, ash, protein and sum of flavonoids was determined in the seed and husk of each buckwheat cultivar. The content of fibre was determined by the Wendee method, using a semi-automatic extraction system Fibretect 2010 (FOSS Analytical). The acids 1.25% H_2SO_4 and 1.25% NaOH were used for extraction. The determination of the ash content was carried out by the weighting method, using a thermogravitational analyzer Eltra TGA (ELTRA GmbH). Samples were combusted at a temperature of 600°C in oxygen atmosphere until constant mass was obtained. The nitrogen content was determined by the Kjeldhal's method according to standard PN-EN ISO 20483:2014-02, using a mineralization and distillation system manufactured by BUCHI (Switzeland). The determined quantity of nitrogen was converted to protein

Common buckwheat (*Fagopyrum esculentum* Moench)



'Red Corolla' 'Karmen' 'La Harpe'

Tartary buckwheat (*Fagopyrum tataricum* Gaertn.)



Lublin accession Olsztyn accession Chinese accession

Photographs 1 and 3–6 magnification 30×, photograph 2 – 100×

Figure. Photographs of cross-sections of achenes of the analyzed buckwheat forms

assuming the coefficient of 6.25. The total flavonoids in achenes was determined spectrophotometrically (Helios γ, Thermo), according to the methodology described by Kwiatkowski (2006).

Bioassays. The development of grain weevil and lesser grain borer on buckwheat achenes was observed in the experiment. Specimens of the two species originated from mass culture maintained at the Department of Entomology, Phytopathology and Molecular Diagnostic of the University of Warmia and Mazury in Olsztyn, Poland. The beetles grew on wheat grain of the cultivar 'Muszelka', under the thermal and humidity conditions which are optimal for these species. The beetles used for the experiment were young individuals (1- to 2-day old) which emerged from seeds after metamorphosis. In our study, beetles were placed on achenes in a sex ratio of 1:1. Sex recognition in *S. granarius* was accomplished by identifying morphological differences between adults, and in *R. dominica* mating pairs were selected. The intensity of the development of pests on achenes of the analysed buckwheat cultivars was assessed according to the number of offspring beetles, amount of produced dust and loss of mass of the achenes. High values of these parameters are correlated with a better habitat for the development of these beetles (Gołębiowska et al., 1976).

Sitophilus granarius. In the experiment, 10 individuals of the grain weevil were placed on the examined plant material in PVC-U containers, and then transferred to a breeding chamber (26°C, air relative humidity 70%). After 15 days, adult forms were removed. An assessment of the number of offspring generation was made from 35th to 65th day of the experiment. Once the experiment was finished, the dust remaining after the foraging by beetles and the buckwheat achenes were weighed so as to determine the loss of mass.

Rhyzopertha dominica. Ten individuals of the lesser grain borer were placed in containers with the analyzed plant material, and then transferred to a breeding chamber, with the temperature set at 28°C and relative air humidity at 70%. The beetles remained on the plant material for 15 days, after which they were removed from the boxes. Like for the other species, hatching adult beetles were counted 35 days after starting the experiment and then removed from the box. After seven weeks of the experiment, dust and buckwheat achenes were weighed.

The experiment was set up in 10 replications. The significance of differences between the means was tested by the analysis of variance (*ANOVA*), assuming that they were significant at $p \leq 0.05$. The calculations were made for real values. The resulting mean values were set in homogenous groups according to the Tukey's test of significance (HSD). Each homogenous group, grouping means not statistically different from one another, was assigned an identical letter index: a, b, c, etc. In order to identify any relationships between selected variables, an analysis of the Pearson's linear correlation was made, determining the value of the coefficient *r*.

Results and discussion

Analysis of physicochemical properties of achenes of the examined buckwheat cultivars. The buckwheat cultivars selected for the experiment

were characterized by morphological differentiation of achenes. The common buckwheat cultivars 'Red Corolla' and 'La Harpe' belong to medium-seed forms with different colours of fruits (spotted brown-black and silver, respectively), shape of the edges of achenes (sharp and rounded, respectively) and mass (medium and high). The cultivar 'Karmen' is a large-fruit form, with the black husk tending to grow into a slightly winged shape. Both Polish accessions of tartary buckwheat are characterized by similar morphological traits of achenes, which are grey in colour, with partly corrugated winged-shaped ends of fruits. Finally, the Chinese form has black achenes, with no wings.

The weight of 1,000 achenes of common buckwheat cultivars was on average more than double that of tartary buckwheat accessions. The highest TSW was determined for the cultivars 'La Harpe' and 'Karmen', while the lowest one was found for the Olsztyn accession (Table 1).

Table 1. Selected physical characteristics of the analyzed buckwheat cultivars

Cultivar	Thousand seed weight g	Husk content %	Husk thickness µm
Common buckwheat			
'Red Corolla'	23.5 b	27.6 b	71.4 c
'Karmen'	29.2 a	25.8 bc	69.9 c
'La Harpe'	29.8 a	22.7 c	64.8 c
Tartary buckwheat			
Lublin accession (LA)	12.2 c	35.9 a	70.4 c
Olsztyn accession (OA)	10.0 e	36.6 a	84.8 b
Chinese accession (CA)	11.0 d	34.5 a	92.9 a

Note. a, b, c ... – means in columns indicated by the same letters do not differ (Tukey's test HSD).

Tartary buckwheat achenes, besides having lower weight, were also distinguished by the lower share of a seed in the fruit (Fig.). The percent contribution of the husk to the mass of an achene in this species was significantly higher than in common buckwheat cultivars. The lowest husk content was determined for the cultivar 'La Harpe' and the highest one for the Olsztyn accession. Two remaining forms of tartary buckwheat analyzed (Lublin and Chinese accessions) were characterized by a significantly larger husk thickness compared to the other forms submitted to our experiment, in which the variation of this trait was small, thus placing them in one homogenous group. Commercially, the most valuable technological characteristics of buckwheat achenes are good grain filling and uniformity, as well as a low hull content (Kalinová et al., 2002). In our experiment, such properties were presented by achenes of the common buckwheat cultivar 'La Harpe'. The large-seed buckwheat cultivars, such as 'Karmen', are often characterized by a lower technological value as raw material for processing because of the high content of husks and a low weight of 1 dm^3 of achenes. Small dimensions of achenes and a thick husk are characteristic features of tartary buckwheat fruits (Bonafaccia et al., 2003; Kwiatkowski, Kłodawska, 2015).

The crude ash content in seeds of buckwheat and in the husk itself was varied and depended on a cultivar (Table 2). The highest percentage of crude ash was determined in the husks of cultivar 'La Harpe', while a very low content of this component was detected in dehulled achenes of Olsztyn accession. Buckwheat seeds contain very small amounts of crude fibre (1.0–2.3% dry matter (DM)), but its husks are a rich source of this ingredient (40.9–60.6% DM). A high fibre content (52.6–60.6% DM) was a distinguishing feature of mainly tartary buckwheat accessions. Total protein was accumulated predominantly in seeds (14.1–17.3% DM) of both buckwheat species, while less protein can be found in the husk (3.2–7.5% DM). A high content of total protein was determined in achenes of the Polish accessions (Lublin and Olsztyn) of tartary buckwheat (Table 2). Flavonoids in common buckwheat achenes were mostly accumulated in the husk, while the seeds contained very small quantities of these compounds. Among the common buckwheat cultivars, the highest concentration of flavonoids, both in seeds and in the husk, was determined in cultivar 'La Harpe'. Achenes of the tartary buckwheat accessions were characterized by an approximately same level of total flavonoids in the husk as common buckwheat, but had on average 30-fold more of these compounds in seeds

Table 2. Selected chemical composition characteristics of the analyzed buckwheat cultivars

Cultivar	Crude ash % DM		Crude fibre % DM		Total protein % DM		Sum of flavonoids mg 100 g^{-1} seeds	
	DA	H	DA	H	DA	H	DA	H
Common buckwheat								
'Red Corolla'	1.64 b	1.63 bc	1.3 c	43.0 e	14.1 f	4.2 c	15 e	194.0 bc
'Karmen'	1.73 a	1.62 bc	1.0 d	46.9 d	14.9 e	3.2 e	19 e	191.0 c
'La Harpe'	1.53 cd	2.44 a	2.3 a	40.9 f	15.9 c	7.5 a	52 d	290.0 a
Tartary buckwheat								
Lublin accession (LA)	1.45 d	1.39 c	2.2 a	60.6 a	17.3 a	4.0 d	981 b	165.0 d
Olsztyn accession (OA)	1.08 e	1.73 b	2.0 b	58.7 b	16.4 b	3.9 d	1083 a	163.0 d
Chinese accession (CA)	1.59 bc	1.64 bc	2.3 a	52.6 c	15.4 d	4.8 b	796 c	200.0 b

Note. DA – dehulled achenes, H – hull of achenes; DM – dry matter content; a, b, c ... means in columns indicated by the same letters do not differ (Tukey's test HSD).

than common buckwheat seeds. Beside this difference in the concentration and localization of flavonoids in the fruits of these two buckwheat species, there were also differences in the profile of flavonoids (Zielińska et al., 2012 a). Attaining a higher content of flavonoids, and especially rutine, in buckwheat seeds is currently one of the basic goals followed in the world's breeding of this crop (Jiang et al., 2006).

Development of Sitophilus granarius. Achenes of the analyzed buckwheat cultivars proved to be a habitat in which grain weevil could develop but its development was worse than in the control treatment ($p < 0.01$) (Table 3).

The count of the offspring generation of this pest developing on the control (56.4 indiv. on average) was significantly higher than in treatments with buckwheat achenes (Table 4). The other analyzed parameters which determined the intensity of foraging by beetles and larvae (dust mass and loss of achene mass) on buckwheat were also significantly lower than in the control treatment. Buckwheat achenes proved to be a rather unsuitable habitat for the development of *S. granarius*, although an acceptable one – which is confirmed by a small number of offspring individuals (0.6 indiv. on average). Moreover, it was found that the analyzed buckwheat cultivars as a habitat significantly differentiated the development of grain weevil (Table 3). The highest abundance of the offspring generation of this species was determined in the treatments with cultivar 'La Harpe' (1.3 indiv. on average) and Tartary LA (1.1 indiv. on average). In these combinations, too, the highest mass of dust was produced by foraging adult forms as well as the highest loss of the mass of achenes were determined (Table 4). The buckwheat cultivars which proved to be the least suitable habitat for the development of *S. granarius* were: 'Red Corolla' and Tartary OA. The average abundance of offspring on these cultivars was 0.1 individual.

Table 3. Results of *ANOVA* for traits connected with the development of *Sitophilus granarius* in tested combinations

With control	SS	df	MS	*F*	*p*
Imagines					
Combinations	26749.7	6	4458.29	95.54	0.00
Error	2939.7	63	46.66		
Mass of dust					
Combinations	1.03	6	0.17	93.55	0.00
Error	0.12	63	0.00		
Loss of weight					
Combinations	44.00	6	7.33	107.51	0.00
Error	4.30	63	0.07		
Buckwheat cultivars	SS	df	MS	*F*	*p*
Imagines					
Combinations	13.55	5	2.71	2.31	0.05
Error	63.3	54	1.17		
Mass of dust					
Combinations	0.01	5	0.00	12.75	0.00
Error	0.01	54	0.00		
Loss of weight					
Combinations	0.13	5	0.03	4.87	0.00
Error	0.29	54	0.00		

SS – sum of squares, df – degree of freedom, MS – mean square, *F* – *F*-value, *p* – *P*-value

Table 4. Development of *Sitophilus granarius* on the analyzed buckwheat cultivars

Combination	Life traits of the storage pest's population					
	adults, pieces		mass of dust g		loss of weight g	
Control						
'Muszelka'	A B	56.4 a	0.360	a	2.333	a
Common buckwheat						
'Red Corolla'	A B	0.1 b a	0.008	b b	0.029	b b
'Karmen'	A B	0.3 b ab	0.004	b b	0.031	b b
'La Harpe'	A B	1.3 b b	0.043	b a	0.163	b a
Tartary buckwheat						
Lublin accession (LA)	A B	1.1 b ab	0.018	b b	0.097	b b
Olsztyn accession (OA)	A B	0.1 b a	0.011	b b	0.051	b b
Chinese accession (CA)	A B	0.4 b ab	0.009	b b	0.054	b b

Note. A – included control, B – without control; a, b, c ... means in columns indicated by the same letters do not differ (Tukey's test HSD).

The most important parameters describing the quality of food for the analyzed stored-food pests are: the abundance of offspring generation, mass of the dust produced during their foraging, and loss of the mass of achenes. High values of these parameters are correlated with a high quality of food for the given species of beetles (Niewiada et al., 2005; Park et al., 2008; Nawrot et al., 2010; Nietupski et al., 2013). Our results suggest that buckwheat achenes create a habitat that is not very appealing to grain weevil. Two factors can play a decisive role: the presence of a tough husk protecting an achene or its chemical composition unsuitable for the adult form of the beetle. Smaller amounts of dust generated by beetles foraging on buckwheat than determined in the control indicate that this species has trouble biting through the husk of an achene in this crop. This makes it difficult for adult forms to ingest food and most probably prevents females from laying eggs. The buckwheat husk also acts as a barrier to foraging *Ephestia kuehniella* (Zeller), *Plodia interpunctella* (Hubner) and *Corcyra cephalonica* (Stainton) (Locatelli, Limonta, 1998). Dehusked buckwheat achenes, on the other hand, are a good habitat for the development of confused flour beetle (*Tribolium confusum* Duv.), second best only to wheat flour (Kordan, Gabryś, 2013).

Development of Rhyzopertha dominica. The lesser grain borer developed on both examined buckwheat species, but the values of the analyzed development parameters of this beetle were significantly lower ($p < 0.01$) than obtained for the control treatment (Table 5). The differences, however, were not as big as in the case of *S. granarius*.

Table 5. Results of *ANOVA* for traits connected with the development of *Rhyzopertha dominica* in tested combinations

With control	SS	df	MS	*F*	*p*
		Imagines			
Combinations	12293.17	6	2048.86	32.98	0.00
Error	3913.40	63	62.12		
		Mass of dust			
Combinations	5.59	6	0.93	43.70	0.00
Error	1.60	63	0.02		
		Loss of weight			
Combinations	6.85	6	1.14	26.48	0.00
Error	2.72	63	0.04		
Buckwheat cultivars	SS	df	MS	*F*	*p*
		Imagines			
Combinations	2645.15	5	529.03	35.60	0.00
Error	802.50	54	14.86		
		Mass of dust			
Combinations	0.30	5	0.06	83.49	0.00
Error	0.04	54	0.00		
		Loss of weight			
Combinations	1.52	5	0.30	69.90	0.00
Error	0.23	54	0.00		

SS – sum of squares, df – degree of freedom, MS – mean square, *F* – *F*-value, *p* – *P*-value

The number of individuals from the offspring generation determined in the control treatment (41.9 indiv. on average) was slightly more than double compared to the buckwheat cultivar most heavily infested by *R. dominica*, i.e. Tartary LA (18.6 indiv. on average) (Table 6). The lesser grain borer beetles foraging on the control object generated significantly more dust (0.89 g) and caused a significantly bigger loss of the grain mass (1.08 g) than in the treatments with buckwheat achenes. Wheat grain belongs to these food products on which *R. dominica* finds highly suitable conditions for development. This is manifested by large quantities of dust generated by foraging beetles and larvae, high losses in grain mass and numerous offspring generations (Gołębiowska et al., 1976; Edde, Phillips, 2006; Kłyś, 2006 a). The original source of food for this species was most probably wood and dried fruits (Jia et al., 2008), which explains why *R. dominica* can forage on food distinguished by considerable toughness. The hard husk proves to be a serious barrier protecting buckwheat achenes from being infested by *S. granarius*, but does not prevent the foraging by the lesser grain borer.

Large, significant ($p < 0.01$) differences were found between the analyzed buckwheat cultivars in their susceptibility to the foraging by *R. dominica* (Table 5). The highest number of offspring beetles was determined in the treatments with achenes of the cultivars: Tartary LA (mean 18.6 indiv.), Tartary CA (mean 14.6 indiv.) and Tartary OA (mean 10.4 indiv.) (Table 6). The pest developed poorly on the other buckwheat cultivars, resulting in about 1.4–3.1 of offspring individuals. The mass of generated dust and loss of the mass of achenes were positively correlated with the abundance of the offspring generation of *R. dominica*.

Physical and chemical characteristic of buckwheat achenes versus the development of pests. The grain weevil proved to be a species which developed very poorly on achenes of the analyzed buckwheat cultivars. The barrier that made this process so difficult was most probably the hard husk, protecting the achene. This is confirmed by the negative correlation ($r = -0.51$) between the abundance of the offspring generation of *S. granarius* and the thickness of the husk in the buckwheat cultivars chosen for our

Table 6. Development of *Rhyzopertha dominica* on the analyzed buckwheat cultivars

Combination		Life traits of the storage pest's population					
		adults, pieces		mass of dust g		loss of weight g	
Control							
'Muszelka'	A	41.9	a	0.89	a	1.08	a
	B						
Common buckwheat							
'Red Corolla'	A	1.4	c	0.03	c	0.14	c
	B		d		c		c
'Karmen'	A	3.1	c	0.06	c	0.21	c
	B		d		c		c
'La Harpe'	A	2.0	c	0.04	c	0.16	c
	B		d		c		c
Tartary buckwheat							
Lublin accession (LA)	A	18.6	b	0.24	b	0.61	b
	B		a		a		a
Olsztyn accession (OA)	A	10.4	bc	0.12	bc	0.32	c
	B		c		b		b
Chinese accession (CA)	A	14.6	b	0.13	bc	0.30	c
	B		b		b		b

Note. A – included control, B – without control; a, b, c ... means in columns indicated by the same letters do not differ (Tukey's test HSD).

study (Table 7). Also, a high share of the husk in the achene's mass was negatively correlated with the number of offspring individuals of this species of beetles ($r = -0.24$). As seen from the experiment by Nawrot et al. (2010), an important role in the choice of food and place for oviposition by *S. granarius* is played by the substances contained in the layer of surface waxes on wheat grain. The absence of such stimulation in the case of whole buckwheat achenes is probably another factor causing the low susceptibility to the foraging by this pest. Gołębiowska and Nawrot (1978) concluded that wheat kernels damaged mechanically or with the removed pericarp were a better source of food than whole grain. The low accessibility of food due to the hard husk and lack of stimulating substances made it more difficult for adult forms of grain weevil to ingest food. According to Gołębiowska (1969), intensive foraging by this pest is a necessary condition for the onset of egg-laying.

Reverse correlations were observed for *R. dominica* – the thick husk and its high share in an achene's mass were positively correlated with the number of offspring beetles, and the values of the correlation coefficient were $r = 0.52$ and $r = 0.87$, respectively (Table 7).

Table 7. Values of the correlation coefficient *r* between the parameters describing the development of the pests and the physicochemical properties of buckwheat achenes and its hulls

Specification		Adults		Mass of dust		Loss of weight	
Sitophilus granarius							
Achenes	Crude ash	0.08	ns	−0.09	ns	−0.12	ns
	Crude fibre	0.59	ns	0.59	ns	0.68	ns
	Total protein	0.57	ns	0.36	ns	0.54	ns
	Sum of flavonoids	−0.03	ns	−0.19	ns	−0.03	ns
Hulls	Crude ash	−0.23	ns	−0.38	ns	−0.39	ns
	Crude fibre	−0.07	ns	′0.34	ns	−0.15	ns
	Total protein	0.68	ns	0.93	$p < 0.01$	0.85	$p < 0.05$
	Sum of flavonoids	0.58	ns	0.83	$p < 0.05$	0.71	ns
	Thousand seed weight	0.21	ns	0.34	ns	0.21	ns
	Hull content	−0.24	ns	−0.44	ns	−0.28	ns
	Hull thickness	−0.51	ns	−0.47	ns	−0.44	ns
Rhyzopertha dominica							
Achenes	Crude ash	−0.38	ns	−0.37	ns	−0.36	ns
	Crude fibre	0.60	ns	0.50	ns	0.44	ns
	Total protein	0.73	ns	0.81	$p < 0.05$	0.83	$p < 0.05$
	Sum of flavonoids	0.89	$p < 0.05$	0.83	$p < 0.05$	0.77	ns
Hulls	Crude ash	−0.36	ns	−0.27	ns	−0.23	ns
	Crude fibre	0.89	$p < 0.05$	0.90	$p < 0.05$	0.87	$p < 0.05$
	Total protein	−0.27	ns	−0.31	ns	−0.32	ns
	Sum of flavonoids	−0.54	ns	−0.56	ns	−0.56	ns
	Thousand seed weight	−0.86	$p < 0.05$	−0.75	ns	−0.68	ns
	Hull content	0.87	$p < 0.05$	0.80	ns	0.74	ns
	Hull thickness	0.52	ns	0.27	ns	0.14	ns

ns – non significant

Crude fibre was that component of the husk whose high content probably stimulated the development of the lesser grain borer. A high content of crude fibre was significantly correlated with the abundance of offspring generation (r = 0.89), mass of dust (r = 0.90) and loss of the mass of achenes (r = 0.87). A higher content of total protein, crude fibre and sum of flavonoids was a stimulant to the development of this pest. In contrast, its development was negatively affected by a higher content of crude ash and fibre (r = −0.23 and r = −0.07, respectively). With regard to the chemical composition of seeds, it was determined that the factors positively correlated with the development of the analyzed pests were elevated concentrations of total protein and crude fibre. In addition to this, the development of *R. dominica* was stimulated by a high content of flavonoids in achenes of the analyzed buckwheat cultivars. In turn, no relationship was found between the content of this flavonoid in achenes and the development of *S. granarius* (Table 7). The lesser grain borer developed more numerously in achenes with the lower values of TSW. Thus, smaller achenes most probably create a better habitat for the development of this pest species, which may be associated with their specific granulation.

Given the choice, when selecting the source of food, *R. dominica* is directed by the presence of aggregation pheromones excreted by males (Khorramshahi, Burkholder, 1981), the nutritional properties of food (Kłyś, 2006 b), granulation of food (Kłyś, 2006 a) and volatile compounds originating from plants (Nguyena et al., 2008; Kłyś, 2011). According to Janes et al. (2012), tartary buckwheat seeds have a strong aroma that is characteristically different form that of common buckwheat. This difference may explain a better development of *R. dominica* on achenes produced by the tartary buckwheat achenes determined during this study. Chanbanga et al. (2008) suggest that beetles of this species prefer rice seeds with a thinner hull, but no such correlation was found in the case of buckwheat achenes.

Conclusion

Buckwheat (*Fagopyrum* Mill.) achenes appeared to be a habitat in which both of the examined beetle species could develop, but the intensity of their development was different. The obtained laboratory study results indicate that lesser grain borer (*Rhyzopertha dominica* F.) can be an actual threat to stored unhusked buckwheat achenes. The physical factor that makes it more difficult for grain weevil (*Sitophilus granarius* L.) to infest buckwheat is most probably the thick husk covering the achene. This factor is not a barrier to the lesser grain borer, which is extremely well adapted to foraging on hard foodstuffs, and the traits which shape the hardness of food (i.e. content of the husk, its thickness and content of crude fibre) can play a decisive role in accepting achenes of a given buckwheat cultivar as food. Moreover, the total protein content and sum of flavonoids in the seed significantly affected the development of this pest species.

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Grikių luobelių fizinių ir cheminių savybių įtaka aruodinio straubliuko (*Sitophilus granarius* L.) ir grūdinio skaptuko (*Rhyzopertha dominica* F.) vystymuisi

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Santrauka

Eksperimento metu nustatytas dviejų rūšių sandėlių kenkėjų: aruodinio straubliuko (*Sitophilus granarius* L.) ir grūdinis skaptukas (*Rhyzopertha dominica* F.), vystymasis tiriant dviejų rūšių grikius: paprastąjį (veislės ‘Red Corolla’, ‘Karmen’ ir ‘La Harpe’) ir totorinį (Olštyno, Lublino ir Kinijos žaliava) grikius. Buvo nustatytos svarbiausios fizinės savybės (1000 grūdų masė, lukšto sudėtis ir storis), grikių sėklų ir lukštų cheminė sudėtis (žali pelenai, žalia ląsteliena, suminis kiekis baltymų ir flavanoidų). Remiantis *R. dominica* ir *S. granarius* vystymosi rodiklių įvertinimu nustatyta, kokios grikių lukštų fizinės ir cheminės savybės turi įtakos šių vabalų vystymuisi. Tyrimai parodė, kad grikių lukštai yra arealas, kuriame abiejų rūšių vabalai gali vystytis skirtinga dinamika. *R. dominica* tinkamesnės sąlygos vystymuisi buvo ant totorinių grikių lukštų, o paprastųjų grikių lukštai buvo mažiau mėgstamas arealas. *S. granarius* tik pavieniai individai vystėsi ant abiejų rūšių grikių lukštų; tai rodo, kad šis maisto šaltinis yra mažiau patrauklus grūdiniam skaptukui. Fizinis veiksnys, lėmęs *S. granarius* neapsigyvenimą ant grikių grūdų – plonas lukštas. Tačiau ši savybė nėra kliūtis grūdiniam skaptukui, ir tai sąlygojo maisto kietumas, t. y. lukšto procentinė dalis branduolyje, lukšto plonumas ir žalios ląstelienos kiekis. Tai gali būti lemiamas veiksnys vabalams renkantis tam tikras grikių rūšis. Kiti faktoriai, kurie turėjo reikšmingos įtakos šių vabalų vystymuisi, buvo didesnis kiekis suminių baltymų ir flavanoidų kiekis sėklose.

Reikšminiai žodžiai: aruodinis straubliukas, fizinės ir cheminės grikių lukštų savybės, grikiai, grūdinis skaptukas, sandėlių kenkėjai.