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EFFECT OF BARLEY AND BUCKWHEAT GRAIN PROCESSING ON THE DEVELOPMENT AND FEEDING OF THE CONFUSED FLOUR BEETLE

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Abstract: The consequences of pearling and cutting (barley *Hordeum vulgare* L.), and roasting and cutting (buckwheat *Fagopyrum esculentum* Möench) on the development and food consumption of the confused flour beetle *Tribolium confusum* Duv. were studied. The factors affecting the increase in the *T. confusum* population, and food consumption effectiveness (the proportion of wasted food in the whole amount of the used product) were different in barley and buckwheat. The best barley product for *T. confusum* was the flour. The population number, the proportion of imagines, and the effectiveness of food consumption were relatively high for cut groats, compared to whole barley. The toughness of the whole groats was most likely the cause of the lowest suitability of this product for the confused flour beetle. Neither the size of the cut groats nor the pearling of barley had any effect on *T. confusum* development and food consumption effectiveness. The best buckwheat product for *T. confusum* was the whole hulled non-processed groats. In these groats, the total population number, the proportion of imagines, and the effectiveness of food consumption were relatively high compared to cut groats. The total population number was the lowest in the steamed groats. The decrease in nutrients and B vitamins due to the removal of the embryo and aleurone layer during the breaking process of buckwheat, was possibly the main factor affecting *T. confusum* development and food consumption in buckwheat.

Key words: *Fagopyrum esculentum, Hordeum vulgare, Tribolium confusum*, storage

INTRODUCTION

Barley (*Hordeum vulgare* L.) and buckwheat (*Fagopyrum esculentum* Möench) are recognized as valuable foods that can successfully replace rice or potatoes on the daily menu. Barley was domesticated about 10,000 years ago (Badr *et al*. 2000). Since then, the acreage of barley cultivation in the world has grown to 55 mln ha, providing 140 mln tonnes of grain per year. Barley is now one of the four major cultivated cereals in the world (Schulte *et al*. 2009). In Poland, there are 974,000 ha of barley grown, which equals 13% of all cultivated land (CSO 2011). Globally, barley is used mainly for feed (55–60%) and malt (30–40%), and only 2–3% is used for human consumption (Ullrich 2011). Nevertheless, there is an increasing interest in the consumption of barley due to its nutritional and medicinal values. Barley foods have high fiber content, they lack wheat-like-gluten protein and have a high content of β-glucans that cause lowering of blood cholesterol level and glycemic index (Baik and Ullrich 2008). In some cultures, principally in Asia and northern Africa, barley has remained a major food source. In Eastern Europe, including Poland, barley groats are still used for preparation of many traditional dishes (Grando 2005; Baik and Ullrich 2008). Altogether, barley groats make up to 70% of all groats consumed in Poland (Grochulska 2008). Buckwheat is one of the traditional crops cultivated in Asia, Central and Eastern Europe (Vojtíšková *et al*. 2012). In many countries such as Poland, Russia, the Ukraine, Slovenia, China, and Japan, groats known as buckwheat-kasha are produced (Dietrych-Szóstak 2006). The world area of buckwheat cultivation is 3 mln ha, and in Poland – 40,000 ha (Chłopicka 2008). Buckwheat seeds are one of the best sources of high quality, easily digestible, glutenless food, rich in potassium, phosphorous, calcium, iron, zinc, vitamins B, E, and rutin (Dietrych-Szóstak 2006; Vojtíšková *et al*. 2012). Moreover, extracts from buckwheat flour show antimutagenic activity, provide protection from oxidative stresses, and have the potential to alleviate diabetes symptoms (Inglett *et al*. 2010). Health benefits of buckwheat have been attributed to the content of several natural antioxidants including tocopherols, phenolic acids, and flavonoids (Dietrych-Szóstak and Oleszek 1999).

For food use, both barley and buckwheat require processing. Processing barley includes dehulling and pearling. Dehulling is the removal of the hull that represents 10–13% of the dry weight of the kernel. Pearling removes the hulls and portions of the outer layers, including al-

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eurone and subaleurone tissues. Hulled or hulled and pearled grain, may be roller milled, flaked, or ground to grits or flour (Balik and Ullrich 2008). In Poland, the following products of hulled and pearled barley are produced and consumed: whole hulled barley as well as fine, medium, and coarse-cut, hulled or pearled barley. Barley flour is used as well. To obtain buckwheat groats of consumption quality, the grain needs to go through a two-step processing: dehulling and roasting. Dehulling involves raising the moisture content of the grain till the dry matter is 22%, followed by heating (10–20 min at 100–150°C), and then a steam treatment. The resulting brown seeds (light buckwheat groats = steamed groats) are ready for cooking or can be roasted (1–2 h, 100–120°C) to produce dark brown groats (=burned groats) (Dietrych-Szóstak 2006).

After processing, the compositon and ratio of nutrients and secondary metabolites in the final products differ from those in whole grain. For example, the soluble dietary fiber and beta-glucan levels increase in pearled barley grain by the removal of up to 30% of the kernel (Ullrich 2011). Dehulling the buckwheat grain by using different temperature regimes resulted in drastic reductions of the total flavonoid concentration in the grain (by 75% of the control), and a smaller but significant (15–20%) reduction in the hulls (Dietrych-Szóstak and Oleszek 1999). Microwave irradiation can be used to obtain buckwheat extracts with higher phenolic content and similar antioxidant activity as those extracts heated in a water bath (Inglett *et al*. 2010). However, in whole groats, microwaving as well as traditional cooking result in a decrease of almost twice the total concentration of flavonoids (Dietrych-Szóstak 2006). On the other hand, processing barley grain prior to feed manufacturing is a common practice to reduce particle size, thereby increasing the surface area of the grain susceptible to the digestive enzymes. The result is generally an improvement in nutrient digestibility and hence enhanced growth performance of an animal (Beauchemin *et al*. 2001; Dehghan-banadaky *et al*. 2007). Interestingly, the roasting process may improve the digestibility of buckwheat while simultaneously decreasing the amount of isolated proteins (Christa and Soral-Śmietana 2008a). A roasted buckwheat diet induced the lowest blood glucose level in diabetic rats, as compared to a steamed and raw buckwheat diet (Choi *et al*. 2003).

Up till now, studies on barley and buckwheat processing effects concentrated mainly on the nutritive and medicinal values of processed grains. Reports on the consequences of the methods and the degree of processing for the products during storage are scarce. There are few reports on how storage-pest insects respond to processed grains and groats. Previous studies dealt mainly with the red flour beetle *Tribolium castaneum* (Herbst) (Meagher *et al*. 1982; Li and Arbogast 1991).

The confused flour beetle (*Tribolium confusum* Duv.) is an omnivorous species, which is responsible for large losses of stored foodstuffs. This beetle causes major economic losses by contaminating food, lowering its nutritive value, creating conditions favorable for mold growth, and decreasing the germination rate by feeding on the embryo (Karnkowski 2000; Kordan 2002; Ignatowicz 2004; Nowaczyk *et al*. 2009). *T. confusum* feeds on cereals, flour, bean, spices, pasta, and many other products, including groundnuts (*Arachis hypogaea*) (Park 1934; Mohale *et al*. 2010). Maize grains, though, are clearly more valuable for the confused flour beetle's development than grains of winter or spring wheat and millet. The higher value of maize grains has been attributed to the different structure of the grains (*e.g.*, the size of the embryo, and the hardness of the grain coat) (Kordan *et al*. 2011a). Moreover, *T. confusum* prefers the grain of wheat cultivars with a low protein content and a poor technological quality of gluten (Laszczak-Dawid *et al*. 2006; Laszczak-Dawid *et al*. 2010). Of the gluten-free flours (rice, maize, buckwheat, multigrain), buckwheat flour is the best food for the confused flour beetle. It is on buckwheat flour that this beetle shows the most rapid development (Kordan *et al*. 2011b). Despite the relatively high content of phenolic acids in hulled buckwheat grain, *T. confusum* can still survive and reproduce for more than 11 weeks (Zadernowski *et al*. 1992; Ciepielewska and Fornal 2004).

The processing of barley and buckwheat alters both the physical and chemical properties of the resulting groats. Considering this fact, the aim of the present work was to study the consequences of different processing methods on the confused flour beetle's food consumption and development. The effect of two physical processing methods that are applied in the commercial preparation of barley and buckwheat were studied: pearling and cutting (barley), and roasting and cutting (buckwheat). Additionally, the size of the cut barley groats was considered.

MATERIALS AND METHODS

Insects

The insects used in the present study derived from the permanent laboratory culture maintained at the Department of Phytopathology and Entomology, University of Warmia and Mazury in Olsztyn, Poland. *T. confusum* was reared in jars (500 ml) with food medium (a mixture of oatmeal, wheat sprouts, wheat flour, and yeast) (Khalequzzaman *et al*. 1994) and kept in an incubator at 30±0.5°C and 75% relative humidity (RH).

Barley and buckwheat products

In the present study, the following barley products were used: whole hulled barley (WHB), cut hulled barley (CHB) (1.5–2.0 mm groats), fine cut pearled barley (FCPB) (1.0–1.5 mm groats), coarse cut pearled barley (CCPB) (2.0–2.5 mm groats), and barley flour (BF). All barley groats were purchased from the MELVIT S.A. company (Warsaw). The barley flour was purchased from Bio-Babalscy (Pokrzydowo). The buckwheat products studied were: steamed buckwheat (SB), burned buckwheat (BB), whole hulled and non-processed buckwheat (WHB), and cut hulled and non-processed buckwheat (CHB). All buckwheat products were purchased from the Artykuły Rolno-Spożywcze Sobków company.

Bioassays

The studied barley and buckwheat products (20 grams) were placed in plastic jars (30 mm high and 80 mm in diameter) and offered to 20 randomly selected young adult *T. confusum* from the stock culture (10 replications for each product studied). The beetles were removed after seven days and the experiment continued for 6 weeks. After that period, the number of larvae, pupae, and imagines of the confused flour beetle were removed and counted. Then, the remains of the food were weighed. In the case of grains and groats, the amount of the dust produced by the insects was weighed as well. The effectiveness of the grain/groat consumption index (CEI) was calculated according to the formula: CEI (%) = $(m_d/m_0–m_t)$x100, where m_d – weight of dust remains, m_0 – weight of the product at the start of experiment, m_t – weight of the product after 6 weeks; $(m_0–m_t)$ – weight of the used product, which is the sum of the food consumed by the insects and the dust remains. The results of the calculation show how much of the used product was not consumed and left as the dust. The higher the value of the CEI (%), the lower the effectiveness of food consumption.

All the experiments were conducted under controlled laboratory conditions in the growing chamber Sanyo MLR 350H at 30±0.5°C and 75% RH.

The statistical analysis was performed on log transformed data (cumulative number of *T. confusum* individuals and weight of the grains and dust) or Bliss-transformed data (proportion of insects of individual developmental stages and CEI) using ANOVA followed by Tukey's test.

RESULTS

Development and food consumption of *T. confusum* in barley products

After the 6-week period of the experimental rearing, the largest number of *T. confusum* was found in the flour. This number was ten times higher than in the cut groats, pearled and unpearled, and 27 times higher than in the whole grain (= whole hulled barley) (Table 1). At the same time, in barley flour, more than 80% of *T. confusum* were imagines. This number was statistically significantly higher than in any other treatment. In the cut groats, the proportion of adults ranged from 21% in cut hulled barley to 62 and 68% in coarse cut pearled barley and whole hulled barley, respectively. As far as the immature stages are concerned, the proportion of pupae was similar in all the products. The least advanced stages – the larvae, were the most abundant in the cut hulled barley and the least abundant in the flour (Table 1, Fig. 1).

The total amount of the product used by the insects was the highest in barley flour. Within grains and groats, the highest amount of the product used was in the fine cut pearled barley, the lowest in whole and cut hulled barley, and a medium amount was used in pearled cut groats of both sizes (Fig. 2). The amount of dust-remains was the highest in the fine cut pearled barley while in the remaining groats and whole grain, the amount of dust-remains was two times (coarse cut pearled barley) to four times (whole grain) lower (Fig. 3). When considering all the grains and groats, the effectiveness of food consumption was relatively low: the amount of not consumed but used products ranged from 60% (coarse cut pearled barley) to 86% (whole hulled barley) (Table 1).

Development and food consumption by *T. confusum* in buckwheat products

After the 6-week period of the experimental rearing, the highest number of *T. confusum* was found in the whole, and cut non-processed buckwheat groats. The number of *T. confusum* was nearly twice as high as in the burned buckwheat and nine times higher than in the steamed buckwheat (Table 1). The highest proportion of imagines among all *T. confusum* occurred in the steamed buckwheat (81%) and the lowest in the cut and non-processed groats (28%) (Table 1, Fig. 4). No pupae

Table 1. Number of the confused flour beetle *T. confusum* (all postembrional stages) and the ceonsumption effectiveness index (CEI) after 6-weeks of development on different forms of barley *H. vulgare* and buckwheat *F. esculentum*. Different letters show statistically significant differences among different forms of barley and buckwheat, respectively (ANOVA followed by Tukey's test; $p < 0.05$)

Product	*Tribolium confusum*				CEI [%]
	total number mean (±SE)	larvae [%]	pupae [%]	imagines [%]	
Barley *Hordeum vulgare*					
Fine cut pearled barley FCPB	26.0 (±4.1) b	40.4 ab	20.8 ns	38.8 bc	76.7 ns
Coarse cut pearled barley CCPB	19.8 (±2.9) b	24.2 bc	13.1 ns	62.7 ab	59.4 ns
Cut hulled barley CHB	21.6 (±2.1) b	66.7 a	12.0 ns	21.3 c	68.0 ns
Whole hulled barley WHB	9.8 (±1.7) c	19.4 bc	12.2 ns	68.4 ab	85.7 ns
Barley flour BF	266.2 (±6.9) a	8.0 c	10.5 ns	81.5 a	–
Buckwheat *Fagopyrum esculentum*					
Steamed buckwheat SB	12.0 (±0.6) c	19.2 c	0.0 b	80.8 a	17.4 b
Burned buckwheat BB	58.5 (±2.8) b	28.7 b	34.5 a	36.8 c	28.5 b
Whole hulled non-processed buckwheat WHB	85.6 (±22.0) ab	14.6 c	20.1 a	65.3 b	30.8 b
Cut hulled non-processed buckwheat CHB	106.0 (±9.1) a	43.7 a	28.8 a	27.5 c	60.5 a

ns – not significant

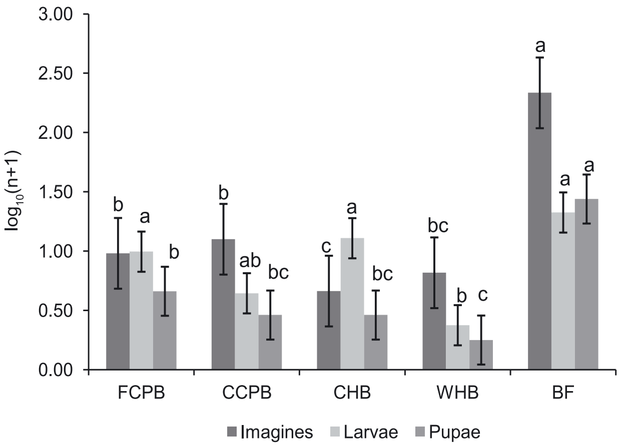

Fig. 1. The number [$\log_{10}(n+1)$] of the adult and immature confused flour beetle *T. confusum* after a 6-week development on different forms of barley *H. vulgare*: FCPB – fine cut pearled barley, CCPB – coarse cut pearled barley, CHB – cut hulled barley, WHB – whole hulled barley, and BF – barley flour. Different letters show statistically significant differences in the number of individual developmental stages in different forms of barley (ANOVA followed by Tukey's test; $p < 0.05$), vertical bars show ±SD

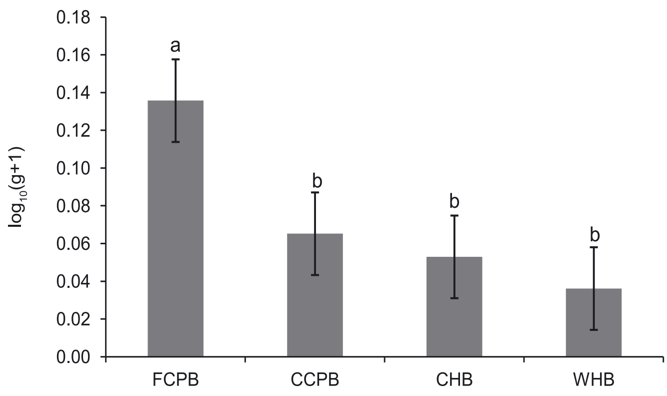

Fig. 3. Amount of dust-remains [$\log_{10}(g+1)$] after the feeding of the confused flour beetle *T. confusum* on different forms of barley *H. vulgare* during the 6-week experiment. FCPB – fine cut pearled barley, CCPB – coarse cut pearled barley, CHB – cut hulled barley, WHB – whole hulled barley. Different letters show statistically significant differences in the amount of dust remains from different forms of barley (ANOVA followed by Tukey's test; $p < 0.05$), vertical bars show ±SD

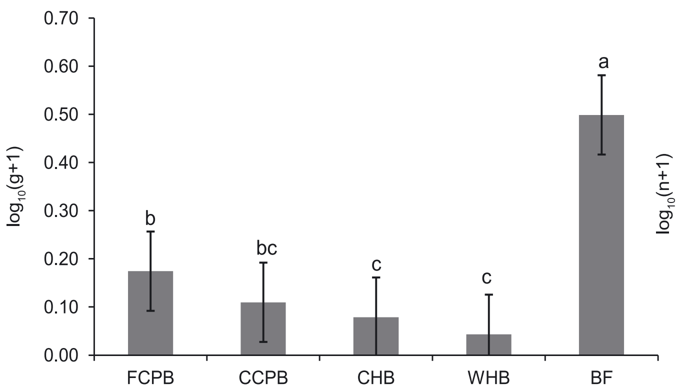

Fig. 2. Dry weight loss [$\log_{10}(g+1)$] of barley *H. vulgare* caused by the confused flour beetle *T. confusum* feeding during the 6-week experiment. FCPB – fine cut pearled barley, CCPB – coarse cut pearled barley, CHB – cut hulled barley, WHB – whole hulled barley, and BF – barley flour. Different letters show statistically significant differences in the amount of the different consumed forms of barley (ANOVA followed by Tukey's test; $p < 0.05$), vertical bars show ±SD

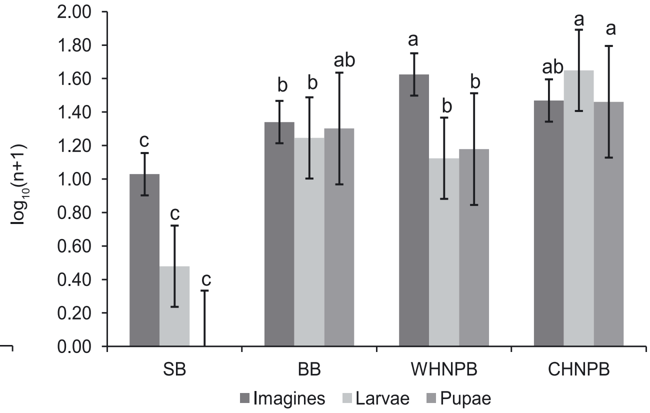

Fig. 4. Number [$\log_{10}(n+1)$] of adult and immature confused flour beetle *T. confusum* after a 6-week development on different forms of buckwheat *F. esculentum*: SB – steamed buckwheat, BB – burned buckwheat, WHNPB – whole hulled and non-processed buckwheat, and CHNPB – cut hulled and non-processed buckwheat. Different letters show statistically significant differences in numbers of individual developmental stages in different forms of buckwheat (ANOVA followed by Tukey's test; $p < 0.05$), vertical bars show ±SD

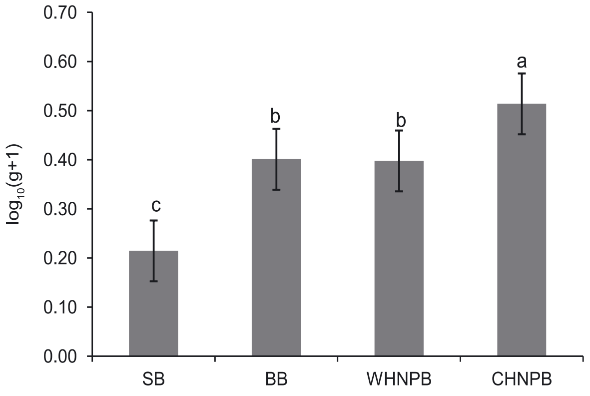

Fig. 5. Dry weight loss [$\log_{10}$(g+1)] of buckwheat *F. esculentum* caused by the confused flour beetle *T. confusum* feeding during the 6-week experiment. SB – steamed buckwheat, BB – burned buckwheat, WHNPB – whole hulled and non-processed buckwheat, and CHNPB – cut hulled and non-processed buckwheat. Different letters show statistically significant differences in the amount of the different consumed forms of buckwheat (ANOVA followed by Tukey's test; $p < 0.05$), vertical bars show ±SD

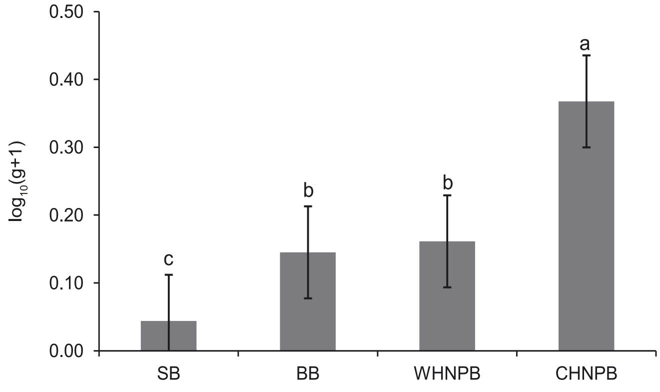

Fig. 6. Amount of dust-remains after the feeding of the confused flour beetle *T. confusum* [$\log_{10}$(g+1)] on different forms of buckwheat *F. esculentum*: SB – steamed buckwheat, BB – burned buckwheat, WHNPB – whole hulled and non-processed buckwheat, and CHNPB – cut hulled and non-processed buckwheat (ANOVA followed by Tukey's test; $p < 0.05$), vertical bars show ±SD

were found in the steamed buckwheat, but the proportion of pupae in the remaining buckwheat products was similar and ranged within 20–35% of the total number of *T. confusum*. As for the larvae, the highest proportion occurred in the cut non-processed buckwheat, and the lowest – in the whole non-processed buckwheat (44 and 15%, respectively) (Table 1).

The total amount of the used product was the highest in the cut non-processed groats and the lowest in the steamed buckwheat (Fig. 5). Likewise, the amount of dust that remained after insect feeding was the highest in the cut non-processed groats and the lowest in the steamed buckwheat (Fig. 6). However, the effectiveness of consumption, which is the proportion of wasted food in the whole amount of the used product, was the highest in the steamed buckwheat and the lowest in the cut non-processed buckwheat (Table 1).

DISCUSSION

As far as barley is concerned, the results of the present study are generally in agreement with the known facts on the confused flour beetle biology. Our results confirmed that the best product of a processed cereal for *T. confusum* development is flour: the population increase and the rate of development were the highest, compared to grains and groats. Within six weeks, almost all progeny of the opening population (the introduced and removed beetles at the beginning of the experiment) completed their development. The length of the *T. confusum* life cycle at 30°C is approximately 30 days (Park 1934). As pointed out by Park (1934), *T. confusum* is unable to feed on whole grains because its mouthparts are not adapted for biting large, hard pieces of food. Indeed, in our study, very few individuals managed to survive on whole barley. The cut groats were more readily accepted by *T. confusum* than the whole grains (the number of surviving insects in the cut groats was twice as high as in the whole grain) but the effectiveness of the food consumption remained low (60–70% waste). Neither the size of the cut groats nor the pearling process of barley had any effect on *T. confusum* survival and food consumption. Meagher *et al*. (1982) found that the population of *T. castaneum* in cracked millet increased faster than in whole grain millet but in the millet flour large numbers of insects were produced. Similar results were obtained by Li and Arbogast (1991) for *T. castaneum* on maize. They found that developmental rates and survival rates were significantly higher on flour and cracked maize than on commercial grain and undamaged grain. They concluded that although damage to grain was not absolutely necessary for young larvae to survive and for females to lay eggs, the fecundity was reduced to a minimum, survival was very low, and development was delayed on undamaged grain (Li and Arbogast 1991).

The results of the present study concerning buckwheat were not as obvious as the results were for barley. The highest number of *T. confusum* occurred in the cut non-processed buckwheat. The development of the insects, though, was rather slow in that product: only 30% of the insects were imagines after 6 weeks of incubation. In contrast, in the steamed buckwheat, the total number of *T. confusum* was the lowest, but the proportion of imagines was the highest. At the same time, in all kinds of whole groats, the effectiveness of food consumption was several times higher than the effectiveness of food consumption in cut groats. In whole non-processed buckwheat, the final number of *T. confusum*, the proportion of imagines in the population, and the effectiveness of food consumption were relatively high, compared to *T. confusum* in steamed buckwheat. On burned buckwheat, the total number of *T. confusum* and proportion of imagines were relatively low but the food consumption effectiveness was comparable to that in whole non-processed buckwheat. The results of this study point to two possible factors that could have affected the *T. confusum* development in buckwheat: breaking of grain, and treatment with high temperatures and low humidity (roasting and burning). The breaking of buckwheat groats causes the destruction and removal of the aleurone layer and embryo, which are rich source of albumins and globulins and B vitamins (Christa and Soral-Śmietana 2008b; Dziedzic *et al*. 2008). According to Park (1934), a high nutritional value of food as well as B vitamins are important in *T. confusum* development and metamorphosis to maturity. At the same time, the roasting process improves the digestibility of buckwheat (Christa and Soral-Śmietana 2008a), and in our study, the roasted groats, especially the steamed ones, were the most effectively consumed groats by the confused flour beetle.

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