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Buckwheat seed quality during the five-year storage in various packing materials

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Abstract: Buckwheat (*Fagopyrum esculentum* Moench.) seed, produced in three locations, was used in the present study. Seed was stored in paper, glass, wood and PVC packing materials under room temperature conditions (18°C) for five years. The following parameters of seed quality were observed: viability, germination, dormancy and a 1000-seed weight. Standard laboratory methods were applied in the studies. The lowest viability after harvest was recorded in seeds stored in glass or PVC packing materials. All factors pointed to a great significance in the expression of viability, germination and seed weight maintenance. The highest value of germination (99%) was recorded in seeds produced in the location Karbulovo after two-year storage in the paper packing material. In the second year of storage, seed dormancy in paper packing material amounted to 0–0.1%. The seed weight changed during the storage period from 33.9 g to 24.4 g. The weight loss was the lowest in seeds stored in the paper packing material. The germination decline was slower in large than in small seeds. Obtained results indicate the importance of packing material for maintenance of seed qualitative traits. According to the gained results, seeds packed in paper packing material mostly retained their physiological and morphological traits.

Keywords: storage conditions; Polygonaceae; grain quality; moisture content; packaging

Buckwheat is one of the oldest plant species originating from Asia. It was cultivated in China thousands of years ago, but it has not found its place in the large-scale agricultural production, yet (Gondola and Papp 2010). However, in recent years, buckwheat has been gaining importance due to greater requirements for plants that provide organic (healthy and safe) food (Halbrecq et al. 2005, Dražić et al. 2016, Ghiselli et al. 2016).

Buckwheat (*Fagopyrum esculentum* Moench.) is an annual plant. Although cultivated in all continents, this plant is economically important for just a few countries (Campbell 2003).

It is a well-known fact that the buckwheat seed is rich in proteins and minerals, certain vitamins (B1, C and E), antioxidants, as well as in polyunsaturated essential fatty acids. The temperature, humidity, chemical impacts, biological conditions of production, harvest, diseases and insects are factors affecting quality parameters during seed storage (Lacerda et al. 2003); moreover seed quality is significantly affected by storage conditions and packing materials (Sinha and Sharma 2004). Seeds with high moisture loose germination capacity and vitality faster. The ageing and weight loss of such seeds are accelerated. Such seeds are prone to infections (Mersal et al. 2006). The responsibility of each seed producer/multiplier is to retain seed quality from harvest to succeeding sowing. Buckwheat seed is dormant after harvest.

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According to the definition of Baskin and Baskin (2004), a dormant seed does not have the capacity to germinate in a specified period of time under any combination of normal physical environmental factors that are otherwise favourable for its germination, i.e., after the seed become non-dormant. Hara et al. (2008), established that the majority of buckwheat seed samples drawn after harvest germinated not sooner than six months after harvest, which was explained by seed dormancy. To provide ever-greater requirements for seed for the production of this plant species, the duration and the method of seed storage have to be adequate. Little data have been found in the literature regarding these issues. Therefore, the objective of this study was to determine physiological and morphological changes in seed traits (quality) during the five-year storage in various packing materials and under temperature conditions of 18°C.

MATERIAL AND METHOD

Seed material. Buckwheat (*Fagopyrum esculentum* Moench.) seed of the cv. Novosadska, developed at the Institute of Field and Vegetable Crops, Novi Sad, was used as a material in this study. This seed was produced in the following three locations: Kušići (K) (43°36'20''N, 20°16'08''E), Karbulovo (KA) (44°13'07''N, 22°25'35''E) and Stara Pazova (SP) (44°59'04''N, 20°09'23''E) in 2012. The standard cropping practices were applied in the buckwheat seed production. After harvest, the seed was cleaned, dried to 14% moisture, and 5000 g of seeds were packed in the paper, glass, wood and PVC packing materials. Then, the seed was stored in a room with no light and at the constant temperature of 18°C for five years (2012–2017).

Laboratory analysis of data. The following parameters were analyzed under laboratory conditions: 1000-seed weight, viability, germination and dormancy. Twelve samples in five replications for each experimental variant were drawn for these analyses. The working sample weight amounted to 60 g. The analytical balance was used to determine the 1000-seed weight (10 replicates of 100 seeds). Seed viability and germination were determined according to the standard procedures prescribed in the ISTA (2012): the between filter paper method in germination cabinets with the application of standard temperature regime (t – 20 <=> 30°C – alternately seven days 16/8 h, white light up to 1200 lux (at 30°C), air humidity up to 60%). Viability and total germination were determined after four and seven days, respectively. The tetrazolium test was applied to separate dormant seeds from the dead ones (ISTA 2012). The first samples for laboratory tests were drawn after 30-day storage and then once a year in the five years of study.

Statistical analysis of data. The obtained experimental data were processed by the mathematical and statistical methods using the IBM SPSS 19.0 statistical package (Armonk, New York). Descriptive statistics were used to process the obtained parameters at the annual level. The differences among the analyzed parameters, as well as their interactions, were determined by the analysis of variance (ANOVA) for the factorial trial set up according to the randomized design as well as by the *LSD* (least significant difference) test at 5% and 1% risk levels. Before the analysis of variance, arcsine transformation ($\sqrt{x}/100$) was preformed for the values expressed in percentages (Snedecor and Cochran 1980). A relative dependence of traits was determined by the Pearson's coefficient of correlation and equations of non-linear regression at the probability levels of 5% and 1%.

Table 1. Analysis of variance (ANOVA) for seed viability, germination, dormancy and 1000-seed weight under impacts of locations, packing materials and storage years

	Viability (a)	Total germination (b)	Dormancy (c)	1000-seed weight (d)
Location (L)	157.284**	219.766**	195.725**	210.160**
Packing (P)	705.778**	848.662**	821.318**	848.662**
Years (Y)	5840.201**	6251.828**	6984.222**	6251.828**
L × P	5.466**	8.781**	7.102**	8.781**
L × Y	4.722**	7.163**	12.189**	7.163**
P × Y	40.204**	42.240**	60.666**	42.240**
L × A × Y	2.055**	2.400**	2.598**	2.400**

a – R^2 = 0.991 (adjusted R^2 = 0.989); b – R^2 = 0.992 (adjusted R^2 = 0.990); c – R^2 = 0.993 (adjusted R^2 = 0.991); d – R^2 = 0.923 (adjusted R^2 = 0.904). *P < 0.05; **P < 0.01; ns – not significant at P < 0.05

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Nonlinear cubic regression:

$$f(x) = ax^3 + bx^2 + cx + d$$

RESULTS AND DISCUSSION

Morphological and physiological traits of seed. The variance of seed vigour, germination, dormancy and weight of over 90% is proportional to the effects of locations, year of storage and the type of packing material (Table 1). The significance of all factors under conditions of room temperature (18°C), as well as their interactions, were determined by the parametric tests ($P < 0.05$, $P < 0.01$).

In the harvest year, 30 days after harvest, the results of viability and germination were lower than the results obtained during the first year of storage. The reason for this is seed dormancy. Thirty days after harvest, seed dormancy ranged from 9.4% in the PVC packing material in the location K to 5.6% in the wood packing material in the location KA (Table 2). A significant reduction in seed dormancy ($P \leq 0.05$) occurred after a year of storage, but to a certain degree, dormancy was still retained and differed over seed origin (location) and the packing material (Table 1).

The highest viability was recorded after the first storage year in seeds packed in glass, wood, and PVC packing materials. During the first two storage years, the seed viability was similar in seeds stored in the paper packing material (Table 2). Previous studies confirmed variability in seed quality in dependence on the type of packing material (Chattha et al. 2012).

Table 2. Mean values of seed viability, germination, dormancy and 1000-seed weight

Packing	Year	Viability			Total germination (%)			Dormancy			1000-seed weight (g)		
		K	KA	SP	K	KA	SP	K	KA	SP	K	KA	SP
Paper	30 days	87.0^{b}	87.8^{b}	84.8^{b}	92.8^{b}	93.8^{b}	91.8^{b}	7.2^{a}	6.2^{a}	8.2^{a}	31.1^{a}	28.2^{a}	33.9^{a}
	1	98.8^{a}	99.2^{a}	98.2^{a}	99.6^{a}	99.8^{a}	99.6^{a}	0.4^{b}	0.2^{b}	0.4^{b}	30.3^{ab}	27.2^{ab}	32.5^{a}
	2	98.0^{a}	98.2^{a}	97.8^{a}	99.0^{a}	99.2^{a}	99.0^{a}	0.2^{b}	0.1^{b}	0^{b}	29.8^{ab}	27.1^{ab}	32.4^{ab}
	3	96.4^{a}	97.0^{a}	95.0^{a}	98.0^{a}	98.6^{a}	97.4^{a}	0^{b}	0^{b}	0^{b}	29.0^{b}	27.2^{ab}	32.3^{ab}
	4	61.0^{c}	64.2^{c}	59.0^{c}	64.8^{c}	70.8^{c}	64.2^{c}	0^{b}	0^{b}	0^{b}	22.5^{c}	25.7^{b}	28.8^{b}
	5	36.4^{d}	40.0^{d}	33.8^{d}	39.0^{d}	43.0^{d}	35.8^{d}	0^{b}	0^{b}	0^{b}	22.6^{d}	24.6^{c}	24.4^{c}
Glass	30 days	82.6^{c}	86.0^{b}	81.4^{b}	84.6^{b}	90.0^{c}	83.0^{c}	8.8^{a}	8.6^{a}	8.0^{a}	30.0^{a}	27.9^{a}	30.8^{a}
	1	92.4^{a}	96.0^{a}	89.0^{a}	94.0^{a}	97.2^{a}	90.6^{a}	1.1^{b}	2^{b}	1.5^{b}	28.6^{ab}	27.2^{ab}	29.1^{ab}
	2	88.8^{b}	92.2^{ab}	83.8^{b}	90.2^{a}	94.6^{b}	86.0^{b}	0^{c}	0^{c}	0.2^{c}	25.4^{bc}	25.7^{b}	27.1^{b}
	3	82.4^{c}	86.4^{b}	79.0^{c}	83.4^{b}	88.6^{d}	81.2^{c}	0^{c}	0^{c}	0^{c}	21.5^{c}	22.8^{c}	26.6^{b}
	4	44.2^{d}	49.6^{c}	36.2^{d}	45.0^{c}	52.6^{e}	37.0^{d}	0^{c}	0^{c}	0^{c}	20.4^{c}	21.9^{cd}	24.6^{bc}
	5	21.8^{e}	27.8^{d}	20.6^{e}	23.4^{d}	29.0^{f}	21.6^{e}	0^{c}	0^{c}	0^{c}	22.1^{c}	18.6^{d}	21.8^{c}
Wood	30 days	86.2^{c}	87.2^{b}	86.0^{c}	90.4^{b}	92.0^{b}	89.0^{bc}	7.2^{a}	5.6^{a}	6.4^{a}	31.0^{a}	27.8^{a}	32.6^{a}
	1	95.8^{a}	98.2^{a}	92.8^{a}	96.8^{a}	99.2^{a}	94.4^{a}	2.2^{b}	1.8^{b}	3.6^{b}	32.2^{a}	27.5^{a}	32.9^{a}
	2	91.6^{b}	96.2^{a}	89.0^{b}	94.2^{a}	98.2^{a}	90.2^{b}	0.2^{c}	0.2^{c}	0.1^{c}	27.9^{b}	26.9^{ab}	31.8^{ab}
	3	88.4^{c}	94.2^{a}	85.6^{c}	89.8^{b}	97.0^{a}	86.6^{c}	0^{c}	0^{c}	0^{c}	29.2^{b}	26.4^{b}	39.7^{b}
	4	46.8^{d}	55.2^{c}	42.0^{d}	49.2^{c}	61.0^{c}	43.2^{d}	0^{c}	0^{c}	0^{c}	24.9^{c}	24.7^{bc}	27.7^{b}
	5	29.6^{e}	33.0^{d}	26.8^{e}	30.0^{d}	36.8^{d}	28.6^{e}	0^{c}	0^{c}	0^{c}	23.9^{d}	24.4^{c}	22.2^{c}
PVC	30 days	82.0^{b}	85.4^{b}	81.4^{b}	83.4^{b}	90.8^{b}	82.0^{b}	9.4^{a}	7.6^{a}	9.0^{a}	29.9^{a}	27.3^{a}	32.5^{a}
	1	87.4^{a}	91.2^{a}	85.6^{a}	89.2^{a}	92.8^{a}	87.2^{a}	4.8^{b}	3.2^{b}	5.8^{b}	28.9^{a}	26.8^{a}	32.0^{a}
	2	82.6^{b}	83.8^{b}	78.6^{b}	84.2^{b}	85.4^{c}	79.8^{c}	0.8^{c}	0.6^{c}	0.2^{c}	24.8^{b}	24.7^{b}	29.0^{b}
	3	60.6^{c}	75.2^{c}	57.2^{c}	62.4^{c}	76.8^{d}	60.4^{d}	0^{c}	0^{c}	0^{c}	20.6^{c}	22.1^{c}	24.4^{c}
	4	35.8^{d}	39.2^{d}	31.2^{d}	37.2^{d}	42.4^{e}	32.6^{e}	0^{c}	0^{c}	0^{c}	20.5^{c}	18.9^{d}	21.5^{d}
	5	13.0^{e}	16.2^{e}	11.2^{e}	15.0^{e}	18.2^{f}	14.0^{f}	0^{c}	0^{c}	0^{c}	18.8^{d}	15.4^{e}	20.3^{e}

K – Kušići; KA – Karbulovo; SP – Stara Pazova; (*LSD* (least significant difference) test, differences in the column are designated with small letters a,b...x, $P \leq 0.05$)

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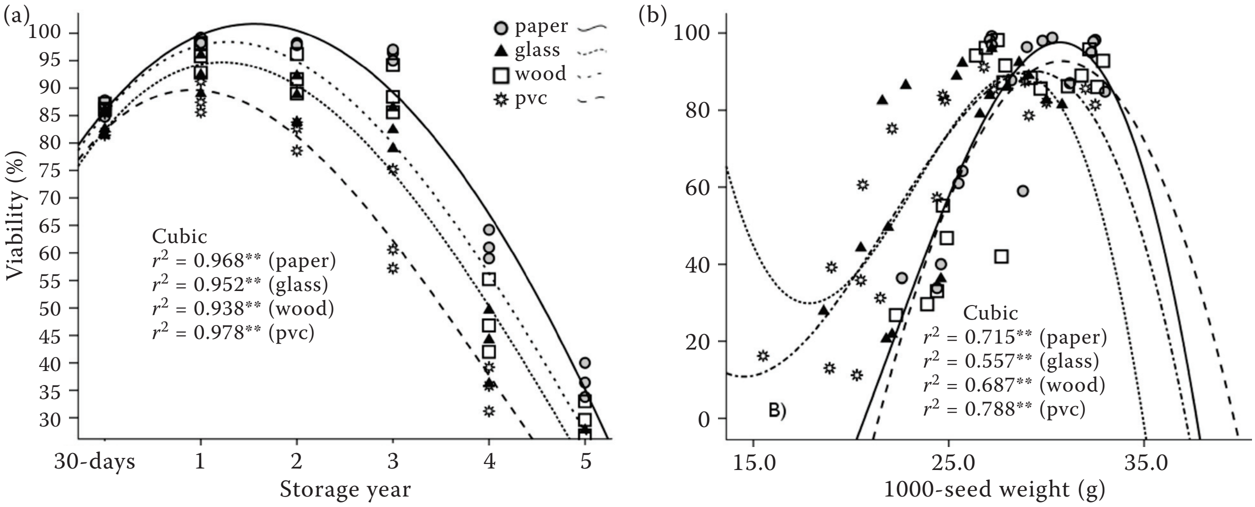

Figure 1. Effects of (a) storage year and (b) 1000-seed weight on seed viability in relation to the packing material. $^{**}P < 0.01$

The determined germination was high in the majority of samples (> 90%). The highest values were registered after the first storage year in seed produced in the location KA. The seed weight was not constant during the storage period. It mostly varied due to the type of packing material. The highest differences in the seed weight were detected in seeds packed in the PVC packing material.

Effects of observed factors on the relation between morphological and physiological traits of seed. Seed viability changes during the storage period, especially in storage premises without control of temperature and humidity conditions (Mohammadi et al. 2012). In the first year after harvest, seeds stored in different types of packing material had similar values of viability after 30-day storage (> 75%). In the succeeding years, differences regarding the types of packing material were obvious. The highest viability was recorded in seeds stored in the paper packing material. Although the viability maximum was detected in seeds after one-year storage, the high degree of viability was retained until the third year of storage in all packing materials except for PVC. The viability decline was the fastest in the PVC packing material. A great dependence of this trait on the packing material and the year of storage ($r^2 > 0.900$) was determined by the application of nonlinear regression (Figure 1a).

The seed ageing rate depends on the capacity of seed to resist deterioration changes and protection mechanisms (Balešević-Tubić and Tatić 2012), which is specific for each plant species, whereby ambient conditions under which seed is stored are important (Nagel and Börner 2010).

Although the seed weight is genetically determined, it is often a result of adjustment to the seed number and thereby to yield (Egli 2006, Sadras 2007). Paper and PVC packing materials affected to the greatest degree the expression of viability ($r^2 > 0.700$) (Figure 1b).

According to Delpérée et al. (2003), buckwheat is susceptible to environmental factors. The positive effects of large seeds on germination were equal in all four packing materials, $r^2 > 0.500$ (Figure 2).

Seed dormancy is a biological trait that makes germination impossible even under normally favourable conditions for germination (Bewley 1997). Due to the intensive process of breeding, seed dormancy decreased or even disappeared in many crops (Adkins et al. 2002). All types of packing material equally af-

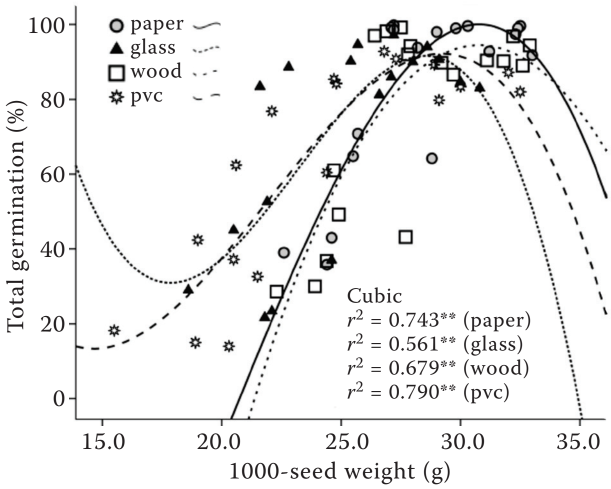

Figure 2. Relationship of seed weight and germination during seed ageing. $^{**}P < 0.01$

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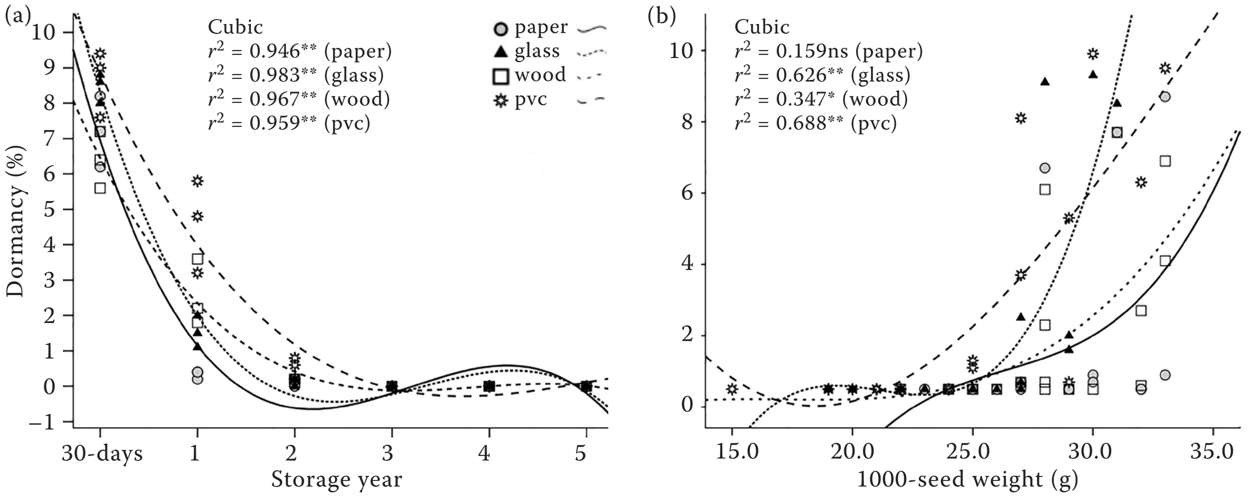

Figure 3. (a) Percentage of dormant seeds over the years of storage and (b) the relation between the dormant seeds and seed weight. *P < 0.05; **P < 0.01; ns – not significant

fected the variability of this trait, r^2 > 0.800 (Figure 3a). The weight, as a morphological trait depending on many factors, mostly affected the percentage of dormant seeds in PVC and glass packing materials. The paper packing material did not affect significantly (r^2 = 0.157) the relation between the weight and the percentage of dormant seeds (Figure 3b).

The greatest variation in germination was recorded in seeds originating from the location K. The glass packing material had the lowest effect on the relation between the weight and the percentage of germinated seeds. The most important effect of the seed weight on germination was determined in buckwheat seeds originating from the location SP and packed in the glass packing material (r^2 > 0.700). A significantly lower effect was detected in seeds originating from the location K also packed in the glass packing material (Figure 4a). The regression equation in which seed origin was also included shows that r^2 coefficient varied from 0.350 to 0.920. Great differences were a consequence of the effects of agroecological factors.

Germination declines with seed ageing. The maximum was recorded in the 1- and 2-year seeds. During the ageing period of buckwheat seed, the importance of seed weight was significant during the second year of investigation, and then as the

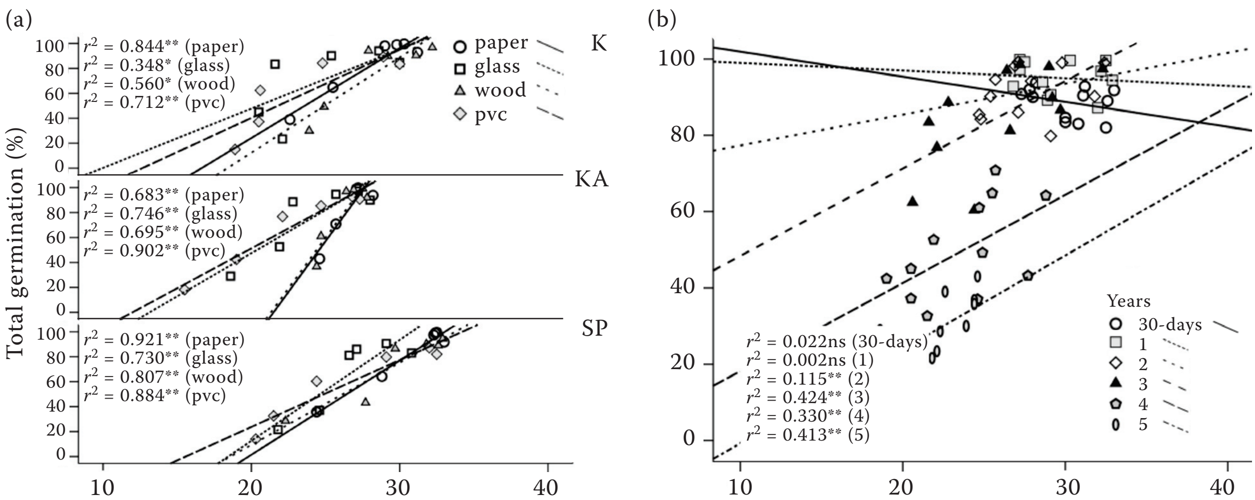

Figure 4. Relationship of seed weight and seed germination during ageing in relation to (a) the packing material and location and (b) years of storage. *P < 0.05; **P < 0.01; ns – not significant; K – Kušići; KA – Karbulovo; SP – Stara Pazova

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seeds aged, the importance of the relation between the number of germinated seeds and the seed weight grew ($P < 0.01$) (Figure 4b). Ageing and germination decline is a consequence of lipid peroxidation, dysfunctional mitochondria or decrease in ATP (adenosine triphosphate) production (McDonald 1999, Basra et al. 2003). These processes depend on seed relative moisture. The moisture content is correlated with lipids. Seeds with a higher lipid content have a lower respiratory threshold and a lower moisture content for the optimum storage.

The packing material affected buckwheat seed viability to the greatest degree during storage. Among tested packaging material, paper proved to be the best since it provided more favorable conditions for the maintenance of high-quality seed than other packing materials.

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