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Moisture induced changes of volume and density of some cereal seeds

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ABSTRACT

The effect of wetting in the density and volume of seeds of barley, rye and two cultivars of wheat was determined. Two levels of wetting were used: (i) 6 h wetting close to the end of imbibition; (ii) 24 h wetting close to the beginning of germination. The experimental results show that the variability of the seeds' volume and density in all tested states can be well described by the Gaussian distribution. The changes of the seed's volume and the seed's density caused by wetting can be then easily expressed via the changes of the distribution parameters. The increase in the seed's density and the seed's volume was the main effect of the wetting, but the level of the observed changes was variable for different crops and different degrees of wetting. Density increase was observed mainly in the case of imbibition, whereas longer wetting was connected mainly with changes of the seed's volume.

Keywords: stored cereals; dormancy; grain; mass; Gaussian distribution

Movement of water into ripe and dry seeds is on one side a critical step in germination and on the other side the critical step of wetting, the undesirable process leading to the losses of both quality and quantity of the stored cereals. The initial part of this process is known with the complex term imbibition (Weitbrecht et al. 2011). During imbibition, the seeds' dimensions start to change as wetting progresses (Dell'Aquilla 2009). Variation in the rate or the pathway of water movement may be affected by the plant species including the dormancy phenotype (Gegas et al. 2010). Most of the biochemical and molecular changes are intensified during the first hours of imbibition and also later during late parts of germination.

In germination, the imbibition process is followed by two more steps (Dell'Aquilla 2009, Rathjen et al. 2009, Weitbrecht et al. 2011). Whereas in imbibition (about 5 h), the seed moisture content steeply increases up to a value representing about a few tens percent increase of the original imbibed seed mass, in germination, there is a second step where the process of wetting stops and then in a third step, the process of wetting continues again up to its end (Weitbrecht et al. 2011). The second and the third steps are very variable depending on the different species and different conditions. At the beginning of the third step, the seed's moisture increases in a short time (its mass approximately doubles). In the remaining part of the third step, further increase of the seed moisture content was not observed.

Seeds have different shapes, so that shape differences can be used for sorting them according to type, cultivar, quality etc. (Dornez et al. 2011, Mebatsion et al. 2012). The volume of the seeds increases during germination and their shape changes even in cases of very symmetric shapes close to the spherical one (Robert et al. 2008). The process of wetting is an inhomogeneous process (Rathjen et al. 2009); so that the seed shape changes due to wetting should be nontrivial (Waszkiewicz 1988). In a previous paper (Blahovec and Lahodová 2014), information on mass and dimensions of some cereal seeds after 10 h and 24 h of wetting was presented in terms of Gaussian distribution. The seed changes during wetting are usually described by changes of its mass; studies on volume, density and porosity changes are more difficult and are

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rather rare even for the seed characteristics in the basic dry state (Chang 1988).

The role of density changes in the early period of germination is not still known, so that in this paper, the volume and the density of some cereal seeds (winter wheat, rye and barley) were studied at the same conditions as in the previous paper with the aim to determine their changes during seeds' wetting.

MATERIAL AND METHODS

The seeds of winter wheat (cvs. Fermi and Sultan), winter rye (cv. Kapitán), and winter barley (cv. Lester) harvested in 2012 (Experimental Station of the University of Life Sciences in Prague-Suchdol) were kept in cold, dry store (temperature below 20°C, humidity below 50%) up to the period of the experiments (September–November 2013). For every tested material, three specimens were randomly selected: I (30 seeds) for determination of moisture content by the gravimetric method, that is based on weighting of the whole specimen prior and after drying (4 h at 104°C, e.g. Sahin and Sumnu 2008). Specimens II and III made off 30 individual seeds, were used for wetting experiments, specimen II for 6 h long wetting and specimen III for 24 h long wetting in distilled water at 25°C.

The wetting experiments were based on measurements in each individual seed. To determine the initial (I) state, every seed was weighted to determine its mass and measured to determine its length (the longest dimension of the seed), its width (the biggest dimension perpendicular to its length) and its thickness (the lowest dimension perpendicular to its length). The dimensions were measured manually using a calliper. The apparent density (Chang 1988) of the individual seeds was determined by further quick weighting of the seed in water of the same temperature (25°C, e.g. Sahin and Sumnu 2008). The volume of each seed was then recalculated as the ratio of the seed's mass and its density. The same measurements were repeated after wetting (W). During the whole process, the identity of each seed was saved. Prior to weighting the seeds in water, the wettability of the seeds was increased by a short cleaning of the seeds in alcohol. The weighting of the seeds in water was done quickly (time less than 10 s) to prevent diffusion of water into the seeds.

The results were statistically evaluated using standard means in Excel.

RESULTS AND DISCUSSION

The initial moisture content (w.b.) of the seeds was 8.1 ± 0.9%. Results for the mean values and the standard deviations for the seed apparent density and the seed volume are given in Table 1. The coefficient of variations (*CV*) of the seed's apparent density was less than ≈5% for each crop (Table 1), whereas the *CV* of the seed volume was less than ≈23% (Table 1). The obtained values of the apparent seed densities in the initial state are lower than the dry matter density of cereals (true density of wheat: about 1450 kg/m^3 given by Chang (1988) or about 1500 kg/m^3 given by Blahovec and Kubát (1987) for pressed barley) so that the initial poro-

Table 1. Basic characteristics

Crop	State	Wetting					
		6 h			24 h		
		MV	SD	*CV*	MV	SD	*CV*
Seeds' apparent density (kg/m^3)							
Barley	initial	1139.1	47.7	4.2	1172.0	54.4	4.6
	wet	1348.7	74.1	5.5	1238.5	41.9	3.4
Rye	initial	1162.4	32.8	2.8	1170.6	61.0	5.2
	wet	1279.9	55.6	4.3	1200.4	47.5	4.0
Fermi	initial	1186.0	40.5	3.4	1205.2	42.7	3.5
	wet	1235.6	51.3	4.2	1222.0	44.6	3.7
Sultan	initial	1197.9	46.5	3.9	1225.7	46.4	3.8
	wet	1256.3	58.5	4.7	1228.6	33.5	2.7
Seeds' volume (mm^3)							
Barley	initial	38.6	5.6	14.6	37.1	6.6	17.8
	wet	44.2	6.9	15.7	51.4	10.1	19.7
Rye	initial	30.6	6.6	21.7	34.5	6.4	18.4
	wet	38.2	8.0	21.0	54.4	10.3	18.9
Fermi	initial	36.9	8.4	22.9	40.8	7.8	19.2
	wet	46.3	10.9	23.5	60.3	12.5	20.7
Sultan	initial	38.4	7.0	18.2	35.6	7.2	20.3
	wet	49.7	9.5	19.1	53.0	10.6	19.9

MV – mean values; SD – standard deviations; *CV* – coefficient of variation (%; *CV* = 100 × SD/MV)

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sity of the tested specimens should be higher than that given by Chang (1988), reaching differences higher than 20% in some cases.

In our case, every individual experimental result represents, among the other 29 ones, 3.33% increase in the cumulative distribution; so that the cumulative distribution of the individual parameter and the individual crop was arranged as a plot of the cumulative coordinate $1/60 + (i - 1)/30$ versus i-th parameter in the increasing set of data. The experimental cumulative distributions were approximated by Gaussian cumulative distributions given by the calculated mean values and the standard deviations. This is given in Figure 1 for the apparent density of barley. This figure shows that the experimental data are well described by the Gaussian distribution. The main differences between the distributions for dry and wet seeds were observed at the lowest values of the apparent densities. The differences from the Gaussian approximation in other parts of the curves in Figure 1 have rather stochastic character and they could represent deviations from the basic Gaussian characteristic of the seed set (Blahovec and Lahodová 2014).

We suppose that the variability of the measured parameters represents superposition of the basic product variability that could be described by the Gaussian parameters given for the individual properties and the variability caused by the measurement method and the parameter variations of the higher order. We can understand the Gaussian

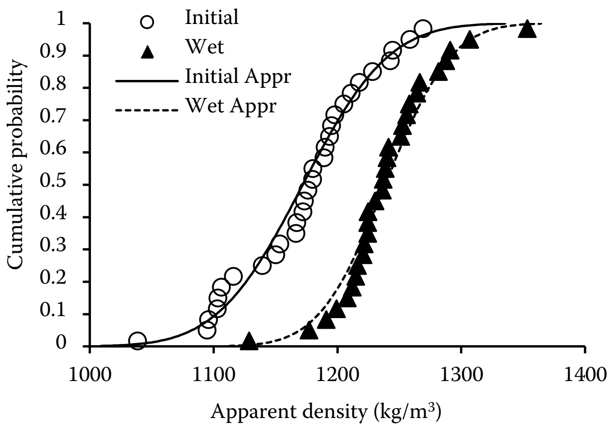

Figure 1. Cumulative probability of seed apparent density plotted against the mass value. The plots were obtained for barley in the test with 24 h wetting. The results are approximated by normal distribution based on the obtained values for the mean value and the standard deviation

equation as an approximation formula for the data expressing their natural variation and the deviations can be described as in other cases of fitting experimental data (Christopoulos and Lew 2000). For evaluation of the fitting, we use RMS (root mean square) defined as:

$$\mathrm{RMS} = \sqrt{\frac{\mathrm{SSE}}{df}} \qquad (1)$$

Where: SSE – sum of the squared differences between the experimental and the Gaussian's values; df – degree of freedom.

It was shown in a previous paper (Blahovec and Lahodová 2014) that RMS for the mass and the seed dimensions is less than 20% of the corresponding standard deviations. Similar results were also observed for the density and the volume of the seeds (as an example, see the differences between the density data and the Gaussian approximation in Figure 1). These results support our hypothesis that the variations of the measured seed parameters can be well described by the Gaussian distribution.

The Gaussian characteristics are also useful for describing relations between two different measurements, e.g. the relation between the same parameter of the seeds of a particular crop, but at different moisture state. Let us have two states of a seed of a crop, I and II, and their property × described by the Gaussian parameters: MV_{xI}, SD_{x1}, and MV_{xII}, SD_{xII}. We can define as the relative crossing point (CP) of the distribution the point x_0 where the standard normal distributions corresponding to both Gaussian plots equal one another, i.e.:

$$(x_0 - MV_{xI})/SD_{xI} = (x_0 - MV_{xII})/SD_{xII}$$

giving the formula:

$$\mathrm{CP} = \frac{x_0}{MV_{xI}} = \frac{SD_{xII}/SD_{xI} - MV_{xII}/MV_{xI}}{SD_{xII}/SD_{xI} - 1} \qquad (2)$$

Other important parameters describing properties of distributions are their standard deviations so that the relation between the standard deviations of the parameters in two states can be described by their ratio:ratio of standard deviations (RSD):

$$\mathrm{RSD} = \frac{SD_{xII}}{SD_{xI}} \qquad (3)$$

The obtained results for CP and RSD for the seed volume and the seed apparent density are plotted in Figure 2. Figure 2a shows that for 6 h wetting CP < 1 and RSD > 1, so that the apparent

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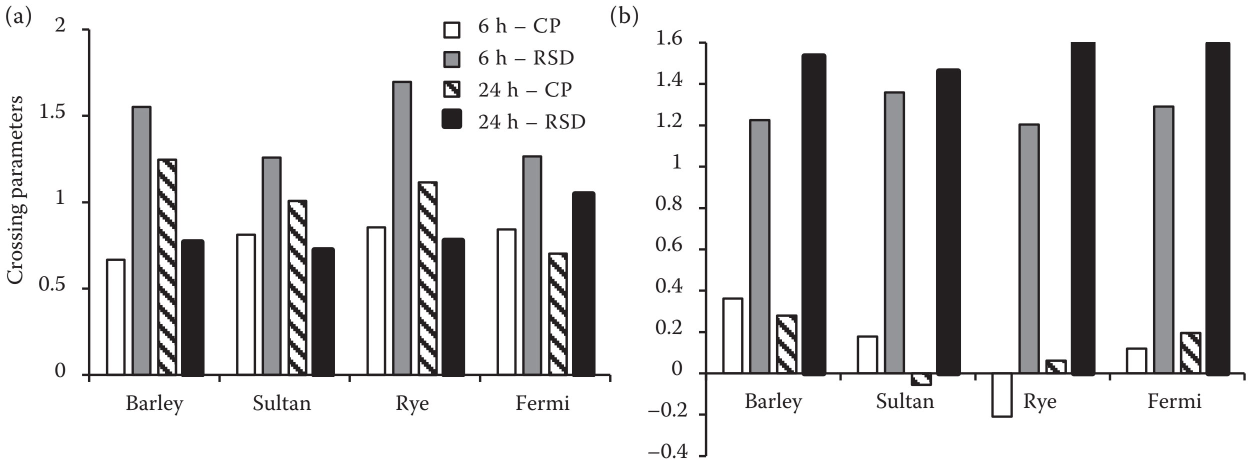

Figure 2. Crossing parameters for the cumulative probability plots versus the measured apparent seed density (a) and the measured seed volume (b). CP – relative crossing point; RSD – ratio of standard deviations

densities of the wet seeds were higher than the apparent densities of the seeds in their initial state. The differences between both plots increased with increasing seed apparent density (the curves are diverging). The results obtained in the 24 h wetting are totally different: CP > 1 and RSD < 1 (Fermi was an exception). It means that in the 24 h wetting, the apparent density was also higher than in the initial state, but the values were converging. The results obtained for the seed volume were different: very low values of the CP and values of the RSD higher than 1 were observed in all cases, so that all cases could be classified as diverging relations with higher volumes in the wet state than in the initial one. The higher RSD values for the 24 h wetting compared to the 6 h wetting indicate higher volumes reached after 24 h wetting than after 6 h wetting.

The changes of the seed parameters during wetting were described by the following description:

$$\mathrm{RCX} = \frac{x_w - x_i}{x_i} = \frac{x_w}{x_i} - 1 \quad (4)$$

Where: RCX – relative change of a parameter x, x_w – parameter x after the wetting; x_i – initial value of x before the wetting.

Volume inspection using Eq. (4) showed that volume changes during seed wetting were relatively stable and relatively independent of the initial values. Figure 3 shows the obtained mean values of volume changes during wetting of different seeds. The lowest values were observed for barley (about 15% increase during the 6 h wetting and about 35% increase during the 24 h wetting). The values for wheat and rye were higher but generally different; differences at 5% level of significance

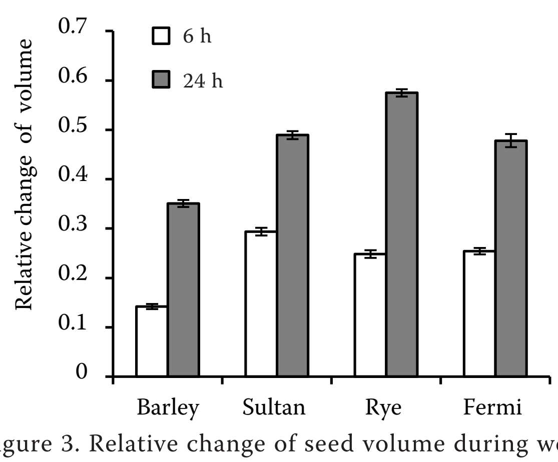

Figure 3. Relative change of seed volume during wetting (6 h and 24 h). The bars denote standard errors

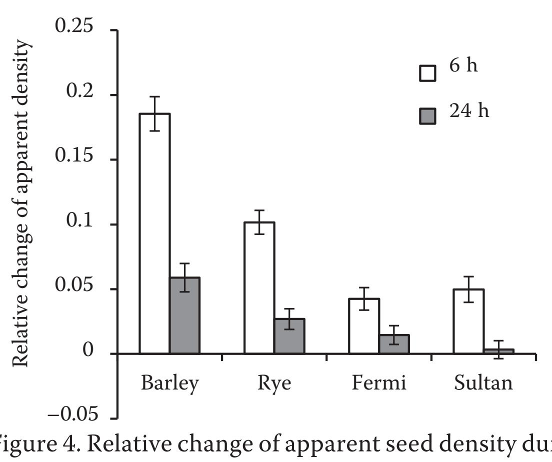

Figure 4. Relative change of apparent seed density during wetting (6 h and 24 h). The bars denote standard errors

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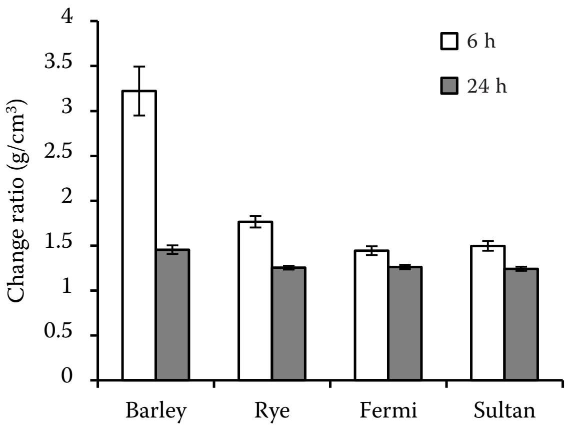

Figure 5. Change ratio due to wetting defined by Eq. (5). The bars denote standard errors

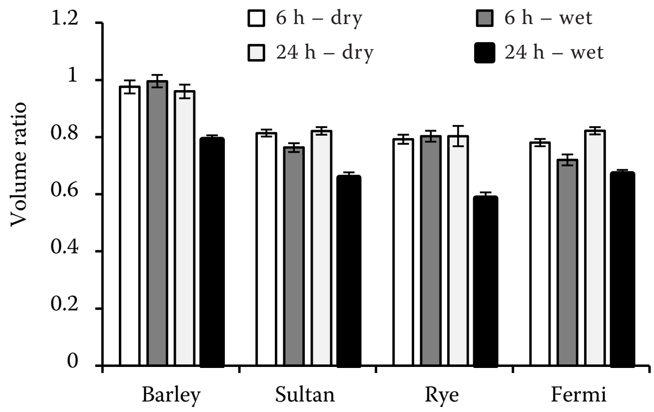

Figure 6. Ratio of the estimated volume from Eq. (6) and volume determined by the two weighting methods. Mean values are plotted, while the bars denote standard errors

were not proven only between Fermi and rye at the 6 h wetting and between Fermi and Sultan at the 24 h wetting.

The changes of the apparent seed densities during wetting were lower than the changes of seed volumes under the same conditions; moreover the density changes were more complicated than the volume changes – they depended more on the initial density as well as on the level of wetting. Mean values of the obtained results are given in Figure 4. Different results were obtained after 24 h wetting: the apparent density changes were lower than at the 6 h wetting. It seems that, during the imbibition, the water filled some part of the internal pores (including of apoplast), especially in denser seeds; their apparent density then increased, whereas in the longer wetting tests some new pores were formed inside the seeds, mainly those of higher initial density (Dornez et al. 2011).

The change of density during the seeds' wetting can be expressed by the following change ratio (CR):

$$\mathrm{CR} = \frac{\Delta m}{\Delta V} = \frac{1}{V}\frac{\Delta \rho}{\Delta V} = \frac{m_w - m_i}{V_w - V_i} \qquad (5)$$

Where: m – mass after wetting (w) and before wetting (i). Similar system of marking was used also for the volume (V).

Change ratio represents the seed's mass increase per unit increase of the seed volume in wetting. Our data plotted in Figure 5 show, that CR after 6 h wetting was higher than after 24 h wetting. Also the values obtained for barley were higher than for the other cases. The values obtained for CR are in agreement with the data of Figure 4.

The volume of agricultural products can be estimated by calculations, using their dimensions. For the agricultural products with shapes similar to an ellipsoid, the volume V_e can be estimated (Sahin and Sumnu 2008) using the following formula:

$$V_e = \frac{1}{6}\pi abc \qquad (6)$$

Where: a, b, c – main axes of the corresponding ellipsoid. We used the basic dimensions of the individual seeds (the length, the width, and the thickness) as the parameters a, b, and c in Eq. (6).

The values obtained for V_e compared with the values of V determined experimentally by calculating the ratio V_e/V (Figure 6). If the ratio equals 1 both quantities are equal. The best agreement was obtained for barley. In the other crops, V_e represented only about 80% of the volume measured experimentally and after 24 h wetting, the agreement was even worse, including the barley seeds. Those results indicate that Eq. (6) could be used only for very crude estimation of the cereal seed volumes.

In conclusion, during the seed's wetting, the apparent seed's density and the seed's volume change. The changes differ for different crops. Generally, the pre-germination can be divided into two parts: the imbibition with characteristic increase of the seeds density and the secondary swelling wetting, where the volume of the seeds increases, while their apparent density decreases. The biggest changes in seed's density during their imbibition are observed in the seeds with the highest initial density. Wetting-induced relative change in seed volume, does not depend on its initial value.

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