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Determination of test weight during threshing by analysing air-filled pore volume in grain fills

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Determination of test weight is a traditional and widespread method to get fast information about grain quality. There are different measuring methods all over the world. Using various analysing methods in different countries can refer to divergent results of the analysis. Furthermore, determination of test weight is influenced by ambient conditions like vibrations, segregation processes or grain properties such as grain geometry. Operators can also influence the results. Due to vibrations or air currents on the combine harvester, for example, it is currently difficult to determine hectolitre mass online during harvest. Constant, defined and especially vibration-free conditions are necessary for the weighing of the individual grain samples. Therefore, Humboldt-Universität zu Berlin has developed a novel system for determining the weight per hectolitre in cooperation with BlueMethano GmbH. In this system, weight is determined by air-filled pore volume of a grain sample. This process does not require a scale, so the system can also be used online on the harvester.

Keywords
Test weight, pore volume, grain quality, grain fills, combine harvester

Test weight has been a common parameter for the fast quality assessment of cereals for many years. Historically, hectolitre mass was used as indicator of flour yield from the individual grains. (Lockwood 1960) Today it is determined both by producers and grain traders and among other parameters in price fixing, test weight is a fast ascertainable indicator of grain quality. (Lee et al. 2000)

Methods for determining test weight vary widely around the world. Due to different measuring setups, there are deviations in hectolitre of the same samples, which were analysed using different methods. All methods have in common that weighing of the samples is necessary. In Germany, a standard chondrometer is used to determine test weight. This has a capacity of 0.5 litres. Using correction tables, the weight determined is then scaled to 100 litres. An online determination during harvest on the combine harvester is difficult, since the vibrations and air flows on the combine harvester can influence the acceleration process of the scales.

In principle, grain quality can also be assessed visually. With the aid of camera images, both the grain shapes and optical conspicuities can be analysed (Berberich et al. 2012). Although this method delivers good results, it requires powerful computing technology for fast online evaluation and is still expensive. In addition, with optical analysis only the surface of grain can be evaluated. Internal ratio of samples cannot be mapped.

Determination of air-filled pore volume of a grain fill does not directly indicate the hectolitre weight. Instead, propositions about the voids within the grain fills can be made. So far, this measuring

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method has been applied analogously, e. g. in soil science (Scheffer and Schachtschabel 2010). These cavities allow conclusions about the internal composition of the grain fill. This is to draw conclusions about foreign impurities, broken or shrivelled grains.

Materials and methods

For evaluation of the relationship between test weight and air-filled pore volume, grain samples from different regions of Germany were analysed. The samples included winter wheat, winter barley, durum and oats. The grain was made available in 2016 by farmers and grain traders from Baden-Württemberg, Bavaria and Thuringia and the Landesamt für Ländliche Entwicklung, Landwirtschaft und Flurneuordnung in Brandenburg. Until analysis, the samples were stored in a cool, dark, dry and airtight place so that physiological changes during storage could be avoided. In order to create conditions as close to reality as possible, samples were not initially sieved or subjected to any other processing.

For the individual tests, the chondrometer „Hecto“ (Pfeuffer GmbH) was used. Weights of the chondrometer content were determined with a balance (Kern PCB 3500-2). The subsequent determination of the air-filled pore volume was carried out using an air pycnometer specially manufactured for the experiments by BlueMethano. In addition, a 100 l vessel manufactured for the tests was used to determine the weight per hectolitre. The weight was determined using a platform scale IFB-100K-3 (Kern & Sohn).

Test setup and procedure

To reference the chondrometer, a preliminary test was carried out. A container with a capacity of 100 litres was filled with different types and varieties of grain. The grain was strucked off the upper edge and weighed afterwards. In order to investigate to what extent vibrations in the environment affect the measurement result, the samples were placed on a vibration platform. After the first weighing, the samples were subjected to a defined vibration for 30 seconds each. Meanwhile, the grain was compacted. The space freed up by the vibration was then filled with the same grain and the samples were weighed again. This was to determine the influence of the filling on the determination of the test weight. At the end of the procedure, a 1 litre retention sample was taken from each 100 litres sample. For this purpose, the contents of the 100 litres vessel were emptied out. A container with a capacity of 1 litre was then inserted into the bulk material and a random sample was taken. The hectolitre weight of this particular sample was then determined using a chondrometer in combination with the associated tables and the results were compared with those of the on-site test (Figure 1).

Figure 1: 100 litres vessel with vibration platform and scale to determine the weight of 100 litres grain (© J. Berberich)

For further experiments the chondrometer, the laboratory balance and the air pycnometer were used. The chondrometer had previously been revised so that the upper and lower cylinders could be separated from each other. In advance, comparative tests have shown that this does not influence the result. However, the separation was necessary for further processing of the samples. First, the chondrometer was filled according to instructions. After that, the analysis was carried out until the grain sample was divided into the parts in the upper and lower cylinders by the cut off slide. The content in the upper cylinder was removed. The cutter was then pulled out and the two cylinders were separated. Now, the lower cylinder with the grain inside was placed in the measuring chamber of the air pycnometer (Figure 2 a). The chamber was sealed airtight and the measurement of the air-filled pore volume was started (Figure 2 b). The air pycnometer consists of a reference chamber and the measuring chamber. Initially, an overpressure of 1 bar was generated in the reference chamber. Both chambers were then connected so that an air exchange could take place. The actual measurement of the air-filled pore volume took place after the pressure in both chambers was balanced. To store and evaluate the measured data, the air pycnometer was connected to a computer via an RS-232 interface. After measurement, the lower part of the chondrometer was removed from the air pycnometer and the grain inside was weighed. This was the most important step in determining the weight per hectolitre. The table enclosed with the chondrometer was used to scale the result into a hectolitre.

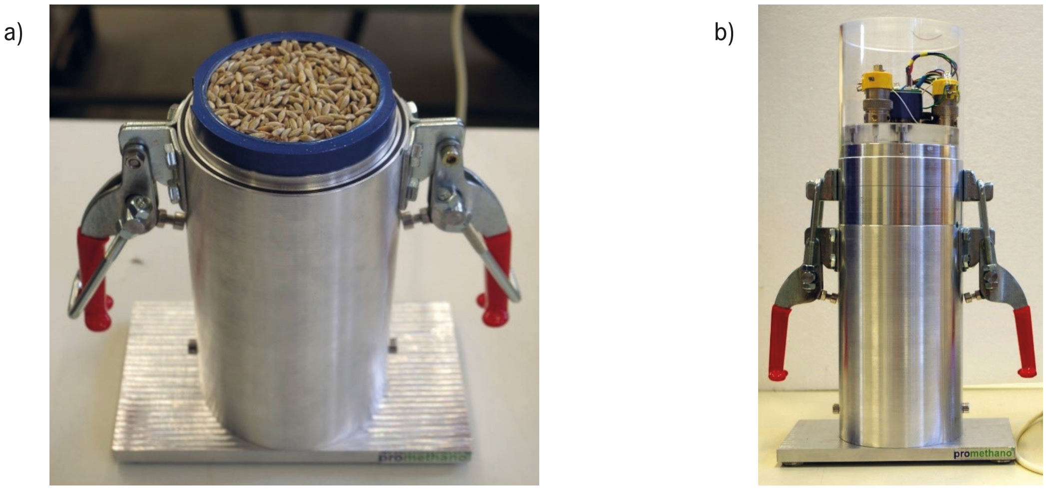

Figure 2: a) Lower cylinder of the chondrometer in measuring chamber of the air pycnometer, b) airtight air pycnometer with cereal samples inside (© J. Berberich)

Using the values of the air pycnometer, the grain volume within the measuring chamber was also calculated. This was basic for determining the internal density or raw density of individual grain types. With different densities of individual species, it would not be possible to determine test weight using the air-filled pore volume. Wheat, rye and barley samples were analysed to check the grain densities. Moisture content of the grain was between 12 and 15%.

Results

The results of the density analysis of individual types of grain wwere decisive for all further investigations. Figure 3 shows that individual wheat samples, with the exception of sample number two, are similar in raw density. The average raw density of wheat is 1.4 g/cm³.

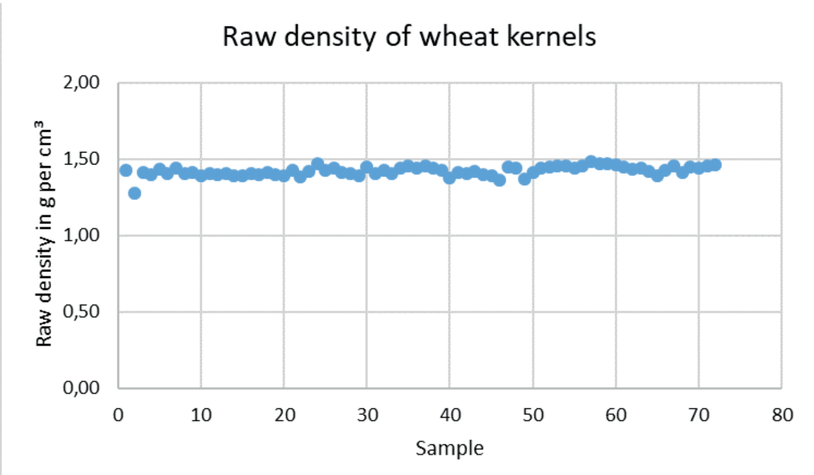

Figure 3: Raw density of wheat kernels

The average raw density of rye is 1,4 g/cm³. Figure 4 also shows that the individual rye samples differ only slightly in raw density.

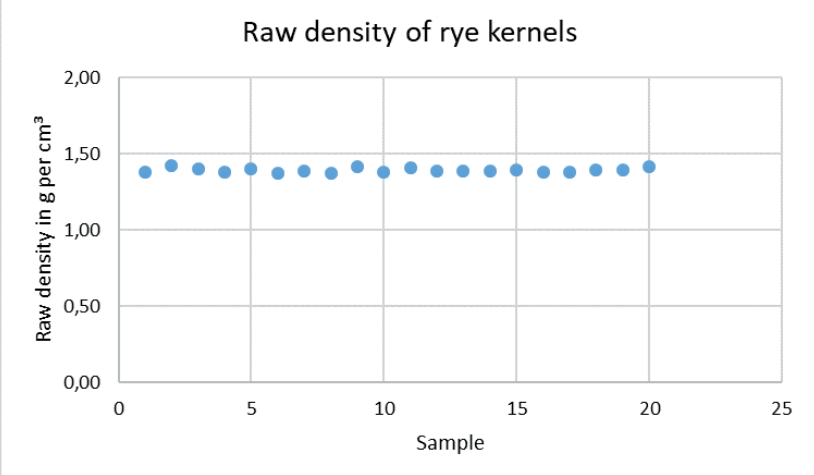

Figure 4: Raw density of rye kernels

Figure 5 shows raw density of the individual barley samples graphically. It can be seen that there are only slight fluctuations between the samples. Average raw density of barley kernels is 1.4 g/cm³.

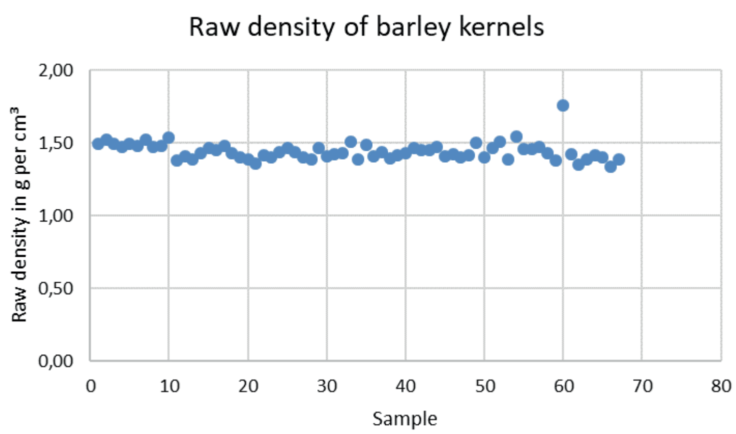

FIgure 5: Raw density of barley kernels

Table 1 shows the results of the tests to determine test weight using the common used chondrometer method in comparison with determination using a 100 litres vessel.

Table 1: Comparison of the hectolitre weights determined by chondrometer and 100 litre vessel.

Grain type	Variety	Test weight chondrometer in kg/hl	Test weight 100 litres vessel in kg/hl	Test weight 100 litres vessel after vibration and refilling in kg/hl
Winter wheat	Bussard	81	81	83
Winter wheat	Bussard	81	81	83
Winter wheat	Akteur	82	81	84
Winter wheat	Akteur	82	82	84
Winter wheat	Bernstein	80	80	82
Winter wheat	Bernstein	80	81	82
Winter wheat	Toras	79	79	81
Winter wheat	Toras	79	79	81
Winter wheat	Alfons	77	77	79
Winter wheat	Alfons	76	77	79
Durum wheat	Durasol	79	79	81
Durum wheat	Durasol	80	81	82
Oat	Mixture	50	50	52
Oat	Mixture	51	50	52
Winter barley	Souleyka	64	64	66
Winter barley	Souleyka	63	64	65

Table 1 and Figure 6 show that conversion of weights determined by the chondrometer using tables supplied by the manufacturer reflects the real weight of 100 litres of each sample. The mean deviation for all samples is 0.5 kg per hl. Average test weight could be increased by 2.14 kg by shaking the sample in the 100 litres container and then filling up again.

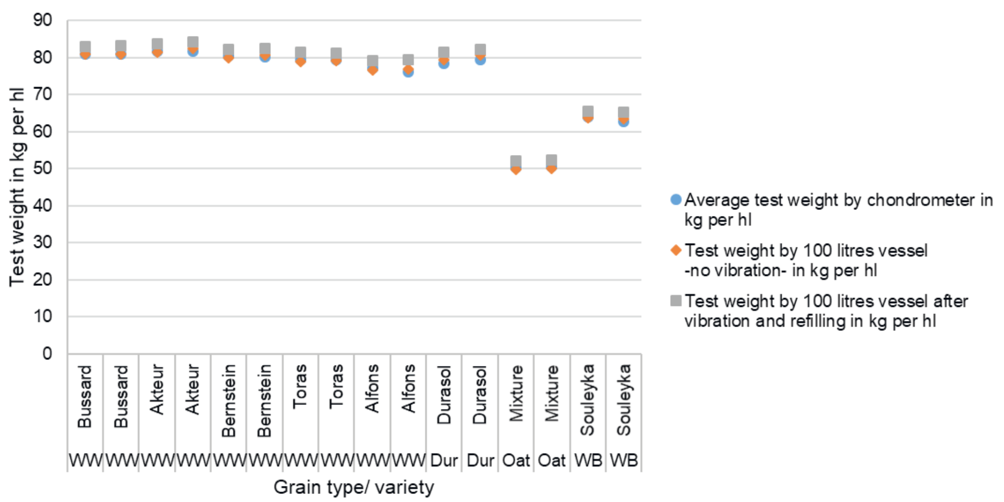

Figure 6: Comparison of test weight determined by 100 litres of grain and hectolitre weight determined with a chondrometer and tables

Results of selected samples from the experiments on the correlation of test weight and air-filled pore volume are shown in Figure 7. There is an indirect correlation between both parameters. This is confirmed by a correlation coefficient of -0.99. High pore volumes thus indicate low test weights and vice versa.

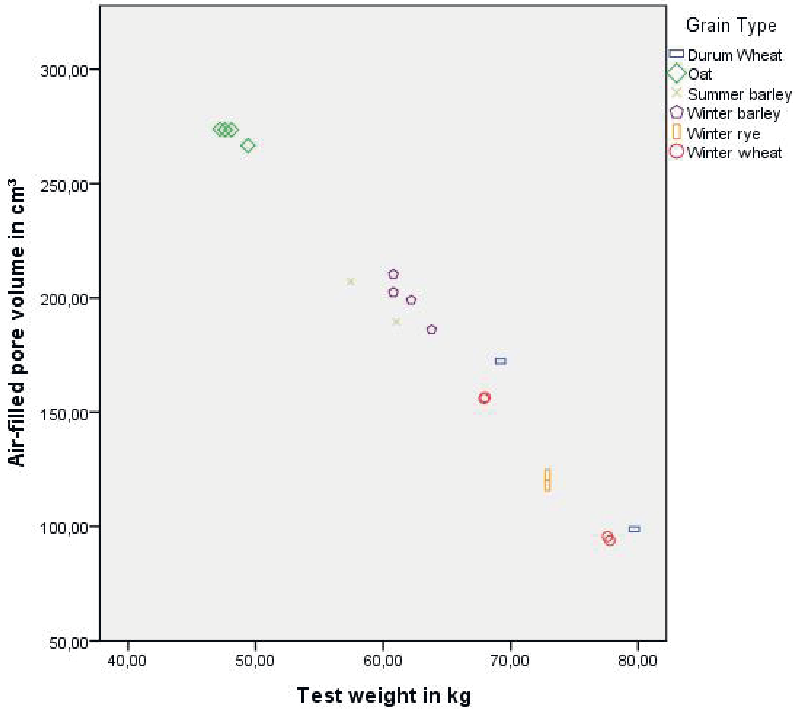

Figure 7: Correlation of test weight and air-filled pore volume

Discussion

Figure 4, Figure 5 and Figure 6 show that raw density of most important cereals wheat, rye and barley is equal to 1.4 g/cm³ under storage-stable moisture contents. This confirms the statement made by Chang (1988), who had already carried out tests to determine raw density of cereal grains using an air pycnometer. Like so, prerequisite for further studies on relationship between test weight and air-filled pore volume in cereals is given.

A reference method is required to analyse correlation between air-filled pore volume and hectolitre weight. The experiments on relationship between chondrometer and real 100 litres weights of grain show that chondrometer is a suitable reference method. Low weight differences between both determination methods can be attributed to the loading of grain into the respective test vessel. With chondrometer, grain is filled by means of a drop weight which displaces air in the lower part of the measuring cylinder. For experiments with the 100 litres vessel, grain was gradually filled with a shovel. This can lead to a more heterogeneous grain fill. In addition, the sample in the chondrometer was one taken from the 100 litres sample, so that sample division error cannot be ruled out. Compaction of grain bulk by means of a vibration also confirmed that ambient conditions may influence the measurement results. This was already shown in previous experiments, in which effects of vibration on the results with a chondrometer were analysed (Berberich 2014)

Indirect proportionality between test weight and air-filled pore volume is shown in Figure 7. This relationship between both parameters allows indirect determination of test weight and without scale. Thus, uncertainties of measurement which normally result from weighing can be minimized. Determining test weight on a combine harvester using conventional methods is difficult due to the prevailing boundary conditions. Online determination of the test weight during harvesting can be realized by means of air-filled pore volume. Thus, farmers always receive up-to-date information about good characteristics of the grain. In addition, yield measurement can be optimised if it is possible to determine mass flow during harvest.

The different geometric material parameters of individual grain types also lead to different arrangement of the grain in the measuring chamber. A perfect spherical packing resulted in an air-filled pore volume of 26%. (Kittel 2013) Figure 7 shows that the percentage air content in the 0.5 litres measuring cylinder of the air pycnometer is always higher because grain kernels are not spherical. Figure 7 also shows that oats have the highest air-filled pore volume. This is due to the shape of the grain, which is the least similar to a sphere of all the cereals analysed. (Donev et al. 2004) The resulting gaps are reflected in the measured pore volume. A time-related analysis of the pressure curves could provide additional information about pore size distribution in the fills. For smaller pores, pressure drop curve would be less steep than for large pores. This would allow a statement about foreign objects in the grain bed and threshing settings could be optimized.

Conclusions

Based on previous findings, conclusions about grain quality, sample composition and threshing quality can be drawn by using test weight. So far, online determination of test weight on a combine harvester has not been satisfactorily solved. Laboratory tests with an air pycnometer show promising results with regard to the indirect determination of test weight via pore volume of grain fills on a combine harvester.

Further experiments are to show how controlled vibration during filling into the measuring chamber has a positive effect on robust measurement results. In addition, temperature influence on measurement results shall be investigated. Laboratory tests showed that temperature differences between stored grain and the compressed air can lead to significant measurement differences. Field trials will show, how these temperature effects can be minimized by using air from the environment of the grain.

In future, the new system may help both farmers and grain traders to quickly analyse grain quality. The measuring system should be able to be used both, stationary and directly on the combine harvester. It may deliver more robust results than previously possible with scales. When used on the harvester, the analysis of the sample composition could also improve threshing quality.

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