Project title

Evaluation of hectolitre mass equipment for oats

Project objective

Evaluation of the hectolitre mass (HLM) equipment used in Australia, Canada, France, Germany, North America and the UK compared to the two-level HLM device used in South Africa to determine the most suitable method and/or equipment for the measurement of HLM for oats

Progress Report
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Introduction

Many grain producing countries rely on hectolitre mass (HLM) as a quality grading factor for major cereal grains. For commercial purposes, oat quality is initially determined by means of grading, based on HLM, presence of foreign matter, and the physical appearance of the grain. HLM has been widely used and accepted in grain marketing systems because it is fast and gives a single, easily interpreted numerical value. Currently there is no international standardised method to measure the HLM of oats, and different countries tend to have their own devices and methods of determination. The basic principle of the method, however, remains the same).

HLM is one of the oldest specifications used in oat grading and serves as a guide for a number of characteristics. HLM, depends not only on the intrinsic quality of the grain, but also on the grain's moisture content; the volume, shape and dimensions of the receiving receptacle of the HLM device; as well as the way in which the receptacle is filled (Anon., 1974). The latter is reported to be affected by kernel and groat size; groat density; hull thickness and length; groat percentage; as well as the presence of awns, diseases, and tertiary kernels (Murphy *et al*., 1940; Forsberg & Reeves, 1992). Other factors such as kernel shape and surface characteristics also affect packing behaviour (Lloyd *et al*., 1999). HLM is also understood to be affected by grain or cultivar type, moisture content and harvest location.

Research aims and objectives

The aim of this study is to assess HLM results obtained with the South African HLM device in comparison with the HLM results obtained from those devices used by other grain exporting and importing countries.

Specific objectives of this study were to evaluate:

- HLM equipment used in Australia, United Kingdom, Canada, France, Germany and North America in comparison to the South African device using selected oat samples with a range of HLM values;
- the effect of rubbing of the oats, before the HLM measurement is performed, on the obtained HLM values; and
- the effect of wetting and drying on HLM results as determined for oat samples.

Materials and methods

Oat samples, sample preparation and hectolitre mass equipment

Commercial home-grown oat samples, with a range in HLM values, were kindly supplied by producers in the Western Cape Province (Kaap Agri; Sentraal-Suid Kooperasie; JH Blanckenberg (Pty) Ltd.). The samples were selected to cover a range in HLM values of *ca.* 10 $kg.hL^{-1.}$ The samples were stored at ambient temperature for a limited period of time before being measured. To prevent insect infestation during that time, particularly the saw-toothed beetle (*Oryzaephilus surinamensis L*.), the samples were regularly sprayed with pyrethroid insecticide.

The samples (*ca.* 1000 g at a time) were rubbed for 5 min in a woven cloth sack, before the HLM measurements were performed. The entire rubbed sample, including the rubbings was used to perform the HLM determinations. The HLM devices used in the study included devices from Germany (Physikalisch-Technische Bundensanstalt, Braunschweig and Berlin, Germany), North America (Seedburo Equipment Co., Chicago, USA), United Kingdom (Farm-tec, Whitby, North Yorshire, UK), South Africa (South African two-level HLM device), France (Chopin Technologies, Villeneuve-la-Garenne Cedex, France), Canada (Dimo's Tool & Die Ltd., Canada) and Australia (Grain Tec (Pty)

Ltd., Peregian Beach, Queensland, Australia, aluminium 500 mL measure with filler and cutter bar) **(Table 1)**. The HLM measurements performed on each device were carried out according to the manufacturers' instructions. During all measurements, care was taken not to tap, knock or shake the respective to prevent a falsely high result to be obtained. All HLM measurements were performed by the same operator and measurements were performed on the devices in random order.

Table 1 Illustration and brief description of the hectolitre devices(HLM) devices

Country	Description of HLM equipment
 **German**	Kern 220/222 Grain sampler with filler and cutter bar. Compliant to ISO 7971-2:1995 (E) standard.
 **USA**	Seedburo 151 Filling Hopper with quart cup and a strike-off stick.
 **UK**	Easi-way Portable Hectolitre Test Weight Kit with cutter bar. Matched to EC 20 L Volume (Directive 71/347/EC) and conforms to ISO 7971-2:1995 and BS 4371 Part 23 standards.
 **SA**	South African two-level HLM device with funnel and 500 mL measuring container and rounded wooden scraper. Measurements for oats are performed on the lower level.
	Nilèma Litre with a filling hopper and cutter bar. Designed in accordance with the AFNOR NF V03-719 (1996) standard and standardised to a 50 L French reference.
 **Canada**	Ohaus 500 mL measure with a Cox Funnel and round wooden striker. 500 mL measure supplied with certificate of calibration (calibrations performed traceable to national standard).
 **Australia**	Aluminium 500 mL measure with filler and cutter bar.

Hectolitre mass equipment and operating procedures

German Kern 220/222 Grain sampler

The sampler is placed on a firm, non-flexible, vibration–free horizontal base. The scraper blade is inserted in the empty 1 litre measuring container. Fill the pre-filling measure with the sample of grain up to the level mark. Then empty it to within 3 cm or 4 cm from the upper edge of the filling hopper in such a way that the grain flows evenly into the middle of the filling hopper in 11 s to 13 s. After filling, quickly pull out the straight edge, but without shaking the device. When the piston and the grain have fallen into the measuring container, place the straight edge back in the slit and push it through the grain in a single stroke. If a particle becomes jammed between the slit edge, the pouring shall be repeated. Throw out excess grain lying on the straight edge. Then remove the filling hopper and straight edge. Weigh the grain (in grams) and read the HLM in $kg.hL^{-1}$, corresponding to the weight of the grain, from the conversion chart supplied with the device.

North America Seedburo 151 Filling Hopper

The funnel (with valve underneath closed), is filled with enough grain to overflow the measuring container (measuring container, quart cup = 1100 mL). Open the valve to release the grain into the measuring cup. Move the funnel to the left side of the measuring cup to provide space on top of the cup. Position the wooden striker on the rim of the cup and remove excess grains by means of three swift full-length zigzag motions. Determine the weight of the grain in the measuring container. Convert the weight of the grain in grams to pounds per bushel ($lb.bu^{-1}$) as indicated on the conversion chart supplied with the device. The obtained value in pound per bushels is converted to $kg.hL^{-1}$ by multiplying it with 1.287.

South Africa two-level hectolitre mass device

Fill the funnel (valve underneath closed) with enough grain to overflow and scrape off excess grains with a rounded wooden scraper. Place the measuring container (500 mL container) on the lower level platform underneath the funnel. Open the valve to release the grain into the measuring container. Move the funnel to the left to create space above the measuring container. Place the rounded wooden scraper on the rim of the container and scrape off excess grains in one quick, smooth motion. Weigh the mass of the grain in the measuring container. Convert the weight in grams to $kg.hL^{-1}$ by dividing it by 5.

Australian aluminium 500 mL measure

The receiving container (500 mL) is mounted on top of the measuring container with a whole at its center. Fill the container with grain through the filler hole. Insert a metal level blade through the slit to isolate the grains from the measuring cylinder underneath. The blade separates a precise volume of grain (below the blade) from excess grains above the blade. The volume of the grain in the measuring cylinder is weighed and converted to $kg.hL^{-1}$ by dividing it by five.

Canadian Ohaus 500 mL measure and Cox funnel

Close the opening of the funnel by inserting the slide into the Cox funnel. Place the funnel on top of the measuring container as such that the notched edge of the funnel fits firmly on the rim of the measuring container (500 mL). Fill the funnel with the grain to more than half. Remove the slide from the opening of the funnel in one quick motion such that the grain flows into the measuring container. While taking care not to disturb the grains in the measuring container, remove the funnel. Place the round wooden scraper on the rim of the container and scalp off excess grains by means of three full-

length smooth zigzag motions. Weigh the mass of the grain in the measuring container in grams. Convert the mass in grams into kg.hL^{-1} using the HLM conversion chart supplied with the device

United Kingdom Easi-way Portable Hectolitre Test Weight Kit

Insert a metal cutter into the slit of the container and drop in the piston (plunger weight) as such that it rests on the cutter bar in the device. Fill the device with the grain at a distance of approximately 2.5 cm above the cylinder. Pull out the cutter bar in one quick motion as such that the piston together with the grain falls to the bottom of the device. Re-insert the cutter bar to separate the grains underneath from excess grains on top of the chamber. Discard excess grain from the cylinder and remove the cutter bar. The weight of the grain in the cylinder in grams is converted to kg.hL^{-1} by reading the corresponding value in kg.hL^{-1} using the conversion chart supplied with the device.

French Nilèma Litre

Place the hopper on top of the one litre measuring container such that the notched edge of the hopper is secured on the container. Close the valve underneath the hopper. Fill the hopper with an even flow of grain. Open and hold the valve to release the grains into the measuring cup. Carefully, insert the straight edge cutter bar into the slit. The container must be held firmly to prevent vibration and compaction of the grains. Remove the hopper from the container and weigh the mass of the grain in the container. Divide the measured mass of the grain in grams by 10 to convert it to kg.hL^{-1}.

Experiment 1: Variation between HLM devices using sub-samples

A schematic layout of the experiment is shown in **Fig. 1**. A 16 kg sample of oats was rubbed as described earlier. The sample was mixed thoroughly by pouring it three times through a Boerner Divider (Seedburo Equipment CO., Chicago, USA). The oats was then divided into 8 times 2 kg sub-samples. Each 2 kg sample was tested on each device, respectively. The order of devices was chosen at random. Ten HLM measurements were performed on each device. However, between each measurement or repetition, the 2 kg sample was always mixed by pouring it from one bucket to another five times.

Experiment 2: Variation in repeatability within and variation between the HLM devices using single work samples

Three different oat samples (16 kg each), with a difference of 3.70 kg.hL^{-1} between the highest and the lowest HLM value, were used. After each sample was rubbed it was mixed thoroughly by pouring it three times through a Boerner Divider. Upon mixing, each sample was divided into 8 times 2 kg samples, where each individual sample was tested on each of the HLM devices respectively. The order of the devices was chosen at random. Ten HLM measurements were carried out on each device using individual samples, i.e. a separate sample for each device. After the first HLM measurement was done, only the grain needed to do the test was used to execute the remaining nine repetitions. The two remaining samples were analysed similarly. A schematic layout of this experiment is shown in **Fig. 2**.

Experiment 3: Comparison of HLM devices using single work samples of 10 oat samples

In this experiment (**Fig. 3)**, ten different oat samples (6 kg each), with a range of 10.50 kg.hL^{-1} between the highest and the lowest HLM value were used. Each of the samples was rubbed and mixed three times using a Boerner Divider.

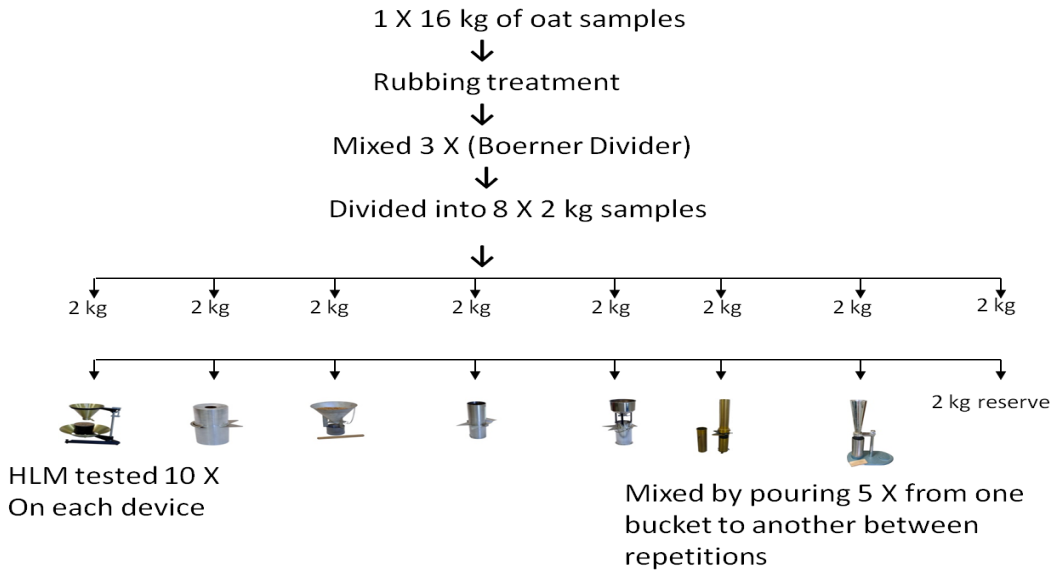

Figure 1 Schematic layout of Experiment 1: Variation between HLM devices using sub-samples.

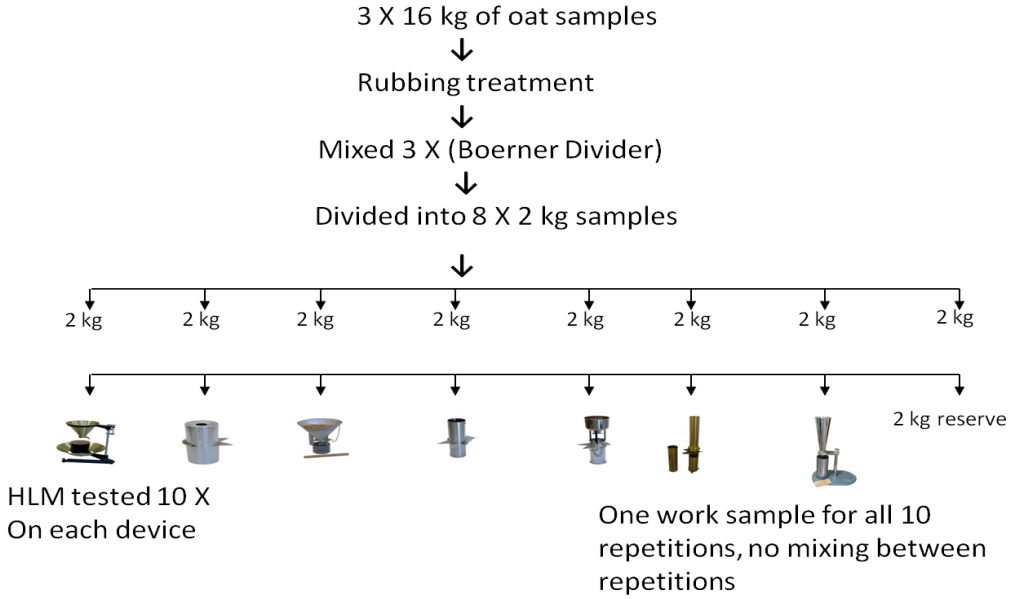

Figure 2 Schematic layout of Experiment 2: Repeatability within the HLM devices using single work samples.

After mixing, each of the 6 kg samples was divided into three times 2 kg sub-samples to be tested on each device respectively. A work sample of the same 2 kg sub-sample was tested repeatedly on all the devices. The first HLM measurement was always performed on the North American device because it requires more grain to do the test than any other device. This work sample was subsequently used to do HLM tests on all the other devices. After the first test was done on the USA device, the order of testing on the other devices was chosen at random. Each sub-sample was measured in duplicate on each respective device, resulting in 6 values per sample per device.

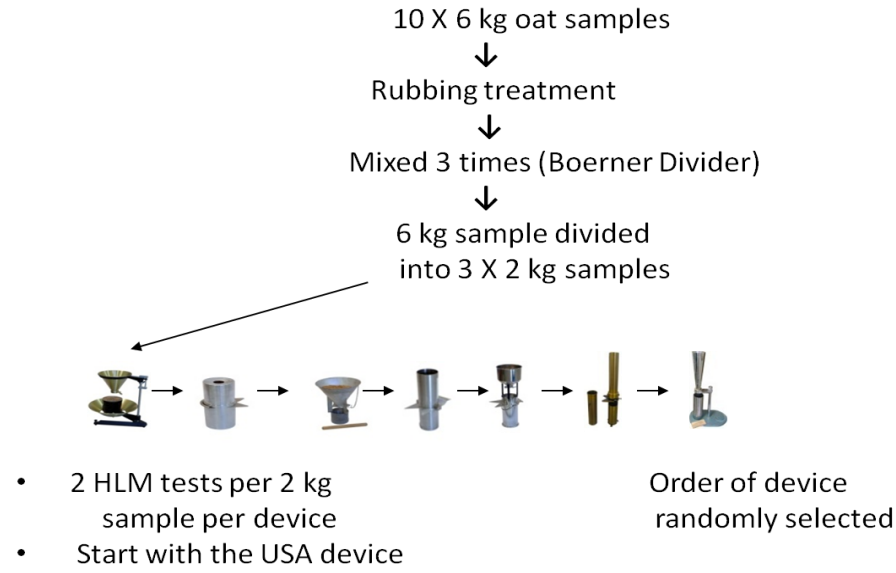

Figure 3 Schematic layout of Experiment 3: Comparison of HLM devices using single work samples.

Experiment 4: Comparison between German and South African devices using sub-samples

Each of three different oat samples (8 kg each), with a difference of 5.93 kg.hL^{-1} between the highest and lowest HLM values, were mixed by pouring it three times through the Boerner Divider. This was done after the samples were rubbed. After mixing, each 8 kg sample was divided into 4 times 2 kg subsamples to be tested individually on each device. Ten HLM measurements were executed on each of two German and two South African devices. However, in between the measurements, the 2 kg was always mixed by pouring from one bucket to another five times. The schematic layout for this experiment is shown in **Fig. 4**.

Experiment 5: The effect of rubbing of oat samples on the HLM values using sub-samples

Fig. 5 shows a schematic layout of Experiment 5. Three different samples each 16 kg with a range of 5.85 kg.hL^{-1} between the highest and the lowest HLM value were used in this experiment. Each of the samples was poured through a Boerner Divider three times in order to get a well-mixed eight times 2 kg sub-samples. With no rubbing done on the samples, each individual 2 kg sub-sample was analysed on each device. The order of the devices was chosen randomly. Ten HLM repetitions were performed on each device for each respective sample. However, between repetitions, the 2 kg sample was mixed by pouring from one bucket to another five times. After the HLM measurements were done, each 2 kg sample was rubbed as described earlier. All the rubbed 2 kg samples were analysed in a similar way to the unrubbed samples.

Moisture content determination

Moisture contents (determination of the weight loss of a sample when dried at 130ºC under specified conditions) were performed according to an adapted method of the AACC 45-15A method (AACC, 2004). The samples were dried in a vacuum oven (Heraeus Model RVT 360, Henau, Germany) at 130°C for one hour. Samples (15 gram) of oats was milled for one minute using a laboratory mill (Retsch model ZMI, Haan Germany) fitted with a 0.5 mm aperture size ring sieve.

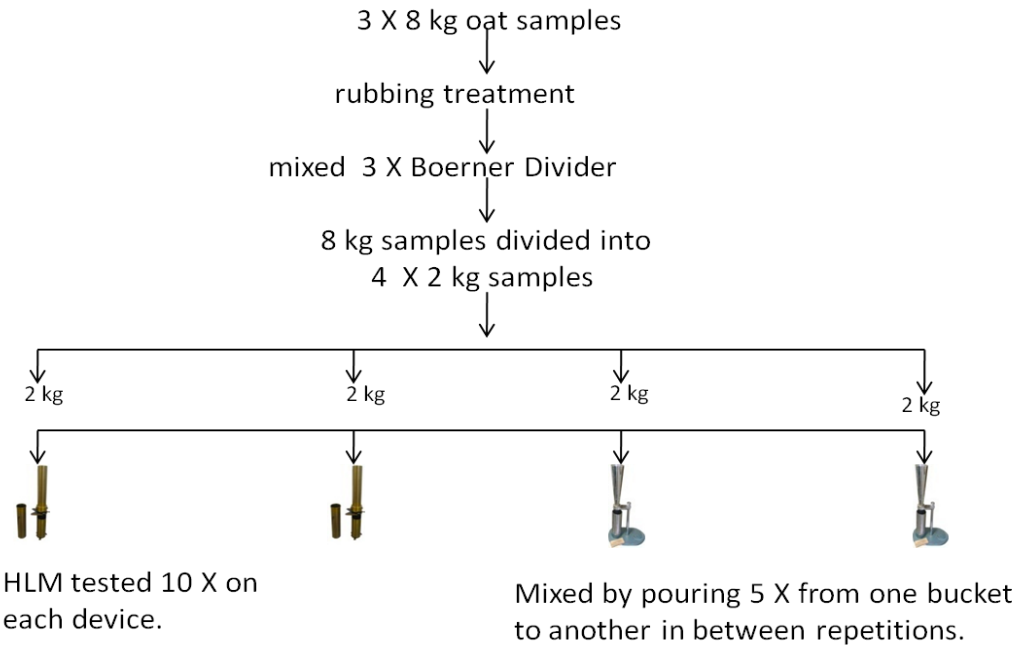

Figure 4 Schematic layout of Experiment 4: Comparison between German and South HLM devices using sub-samples.

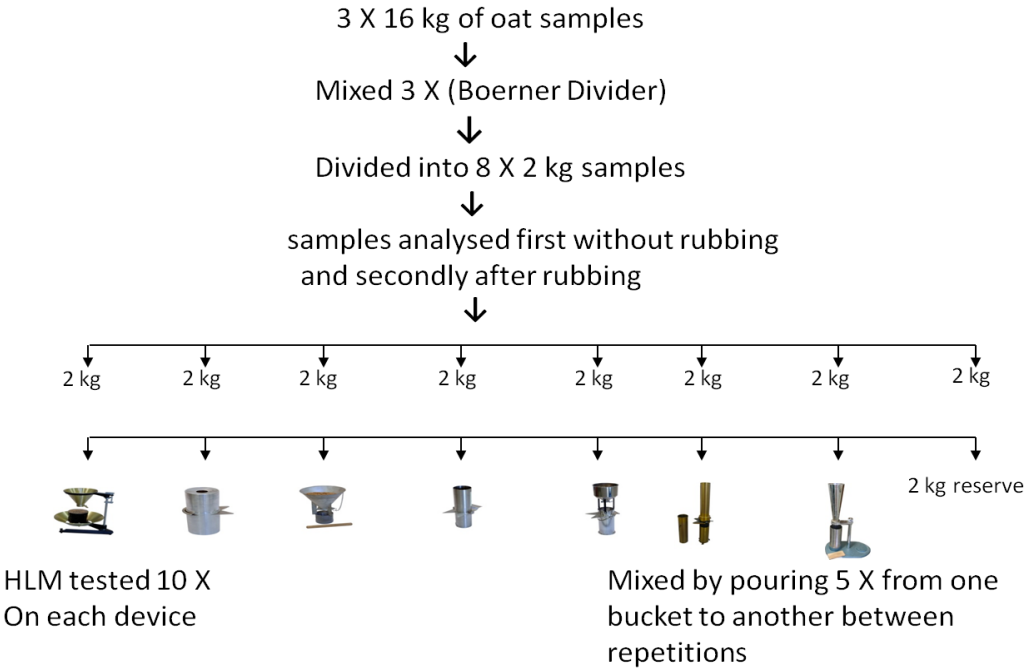

Figure 5 Schematic layout of Experiment 5: Effect of rubbing of oat samples on the HLM values using sub-samples.

The ground sample was transferred into a container, mixed with the spatula and covered with parafilm until being weighed. Moisture dishes were dried in a vacuum oven at 130°C for 30 min and cooled in a desiccator for 40 min. The weight of the pre-dried moisture dishes with lids were determined (recorded to at least 0.001 g). The sample to be dried (5 ± 0.001 g) was transferred into the moisture dishes. Moisture dishes were placed in a vacuum oven with lids next to them and samples were dried at 130°C

for one hr. Afterwards, the moisture dishes were removed from the oven, covered with lids and transferred to the desiccator to cool for 45 minutes. The new mass of the covered moisture dishes with dried sample was recorded to the nearest 0.001 g. Moisture content was calculated as the loss in weight, expressed as a percentage of the weight of the original sample.

Experiment 6: Effect of consecutive wetting and drying of oat samples on HLM results

Four samples (8 kg each), with a range of 10.91 $kg.hL^{-1}$ between the highest and lowest HLM values, were rubbed and used. Each 8 kg sample was divided into four sub-samples of 2 kg each. Three of the four sub-samples were conditioned to a moisture content of *ca.* 14, 16 and 18% respectively. The remaining sample was kept at its original moisture content (ca. 10%). The samples were conditioned by adding appropriate amount of deionised water to obtain the desired final moisture contents, respectively. The starting point of wetting the grains was to determine its original moisture content. This was used to determine the amount of water needed to wet the grain to respective moisture content levels. The amount of water required to wet the grain was calculated using the following equation:

$$\text{required } H_2O \text{ (mL)} = \frac{\text{mass (g)} \times [\text{target moisture \%} - \text{initial moisture \%}]}{[100 - \text{target moisture content}]}$$

where
required H_2O (mL) = amount of water to be added to oat to reach a desired moisture content.
mass (g) = mass of oat to be conditioned.
Target moisture % = *ca.* desired moisture content of oat after conditioning
Initial moisture % = original moisture content of oat before conditioning

Researchers know from experience that when the calculated amount of water is added to the oats, it does not result in the expected moisture content. It is presumably due to the increase in total mass of the wetted oats after the water has been added to the oat samples. It was suggested that an additional 8% of water was added to correct for this difference. Immediately upon adding the water, the samples were mixed thoroughly by shaking the containers for five min. The containers were constantly shaken at regular intervals for the first one hr of wetting. The samples were left to equilibrate at room temperature for 24 hrs. After 24 hrs, the samples were mixed again for five min and were stored at 4ºC for an additional 24 hrs. The samples were then allowed to equilibrate to ambient temperature and relative humidity. This was achieved by spreading the samples in a single layer for one hr. The moisture contents of the conditioned oats were confirmed according to the one-hour oven method.

The HLM of all sub-samples were measured in duplicate on each of the seven different devices. The first measurement was performed on the North-American device whereby the work sample obtained was used to perform HLM measurement of the samples on other devices in random order. All the samples were then dried in a forced circulation heating room at *ca.* 35ºC to a moisture content of *ca.* 10%. The moisture contents of the dried samples were again confirmed by the one-hour oven method and the HLM of all the samples again determined as described above. All the samples were again conditioned to their original moisture content before drying, i.e. original, 14, 16 and 18% respectively. The moisture contents of all samples after each respective conditioning treatment are shown in **Table 2**.

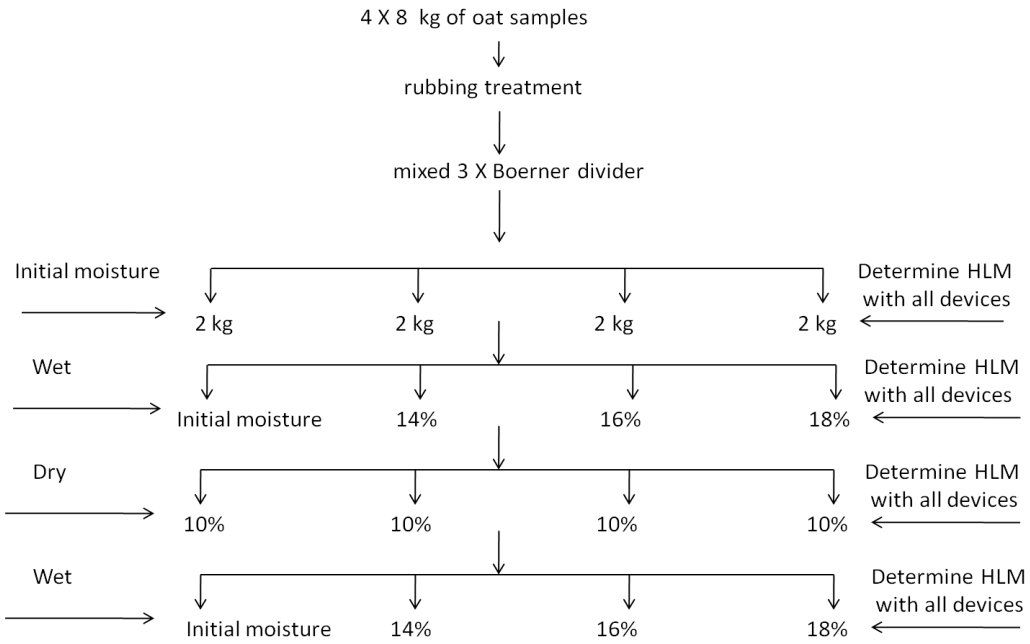

Figure 6 Schematic layout of Experiment 6: Effect of consecutive wetting and drying of oat samples on hectoliter mass (HLM) results.

Table 2 Moisture contents of oat samples after consecutive wetting and drying steps

Moisture treatments	**Moisture content (%)**			
	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**
Control sample	11.5	10.8	11.3	10.9
Conditioned to *ca*. 14%	13.5	13.7	13.3	13.9
Conditioned to *ca*. 16%	15.3	15.8	16.1	15.1
Conditioned to *ca*. 18%	17.6	17.0	16.9	17.5
Drying control sample to *ca*. 10%	9.7	9.4	10.1	10.2
Drying 14% to *ca*. 10%	9.2	9.8	9.8	9.7
Drying 16% to ca. 10%	10.1	9.9	10.2	10.2
Drying 18% to *ca*. 10%	10.9	9.8	10.6	9.9
Conditioned back to initial moisture	11.2	10.4	11.5	10.5
Conditioned back to *ca*. 14%	14.2	13.8	13.7	14.4
Conditioned back to *ca*. 16%	15.6	15.3	15.8	15.2
Conditioned back to *ca*. 18%	17.0	17.4	17.2	17.6

Statistical analysis

Statistical analyses were performed and graphs compiled using Statistica version 10 (StatSoft, Inc., Tulsa, OK, USA). Repeated measures analysis of variance (RANOVA) was performed to compare average measurements between instruments to determine absolute differences. The bar around the average represents the 95% confidence interval for the average measurements. Fischer least significant difference (LSD) *post-hoc* testing was used. All references to significant differences indicate statistical differences.

Additionally the intra-class correlation (ICC) coefficients were determined as the ICC agreement that correlates measurements with each other, while taking into account the differences in absolute

values of the respective measurements, and the ICC consistency that only correlates measurements. All ICC calculations were done using the R statistical programming language.

Results and discussion

Experiment 1: Variation between HLM devices using sub-samples

Fig. 7 shows the mean HLM values obtained from the respective HLM devices when only one oat sample was used. The average HLM measurements obtained from the German, Canadian, Australian, UK and French devices did not differ significantly ($P>0.05$). However, significantly ($P<0.05$) lower HLM values were obtained from the South African and North America devices. The latter two devices also differed significantly ($P<0.05$). The possibility of a sample effect should be considered as only one sample was used during this initial experiment.

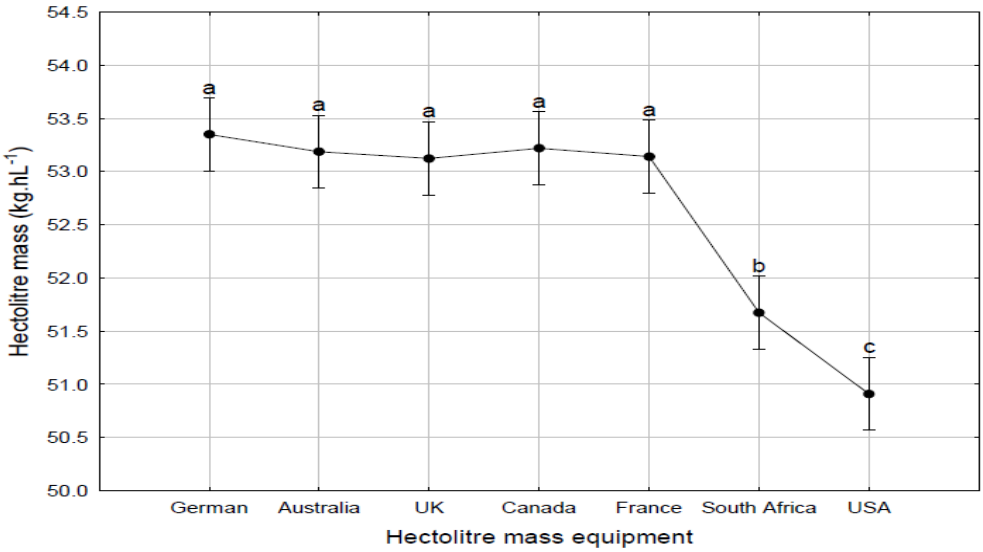

Figure 7 Differences between the average hectoliter mass (HLM) values, obtained with the HLM devices using a single oat sample, as determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant (LSD) *post-hoc* analysis. Vertical bars denote 0.95 confidence intervals.

Experiment 2: Variation in repeatability within and variation between the HLM devices using single work samples

Irrespective of the HLM device and/or sample used, no significant differences ($P>0.05$) were observed between the ten repetitions performed on any of the samples with any of the devices. Examples of results obtained can be seen in **Fig. 8**. This indicates that irrespective of the number of times a sample went through a device, the HLM values did not change significantly between the first and last analysis. This confirmed efficient sample preparation in terms of rubbing, mixing and sampling. All samples used in the remaining experiments were thus prepared in the same way.

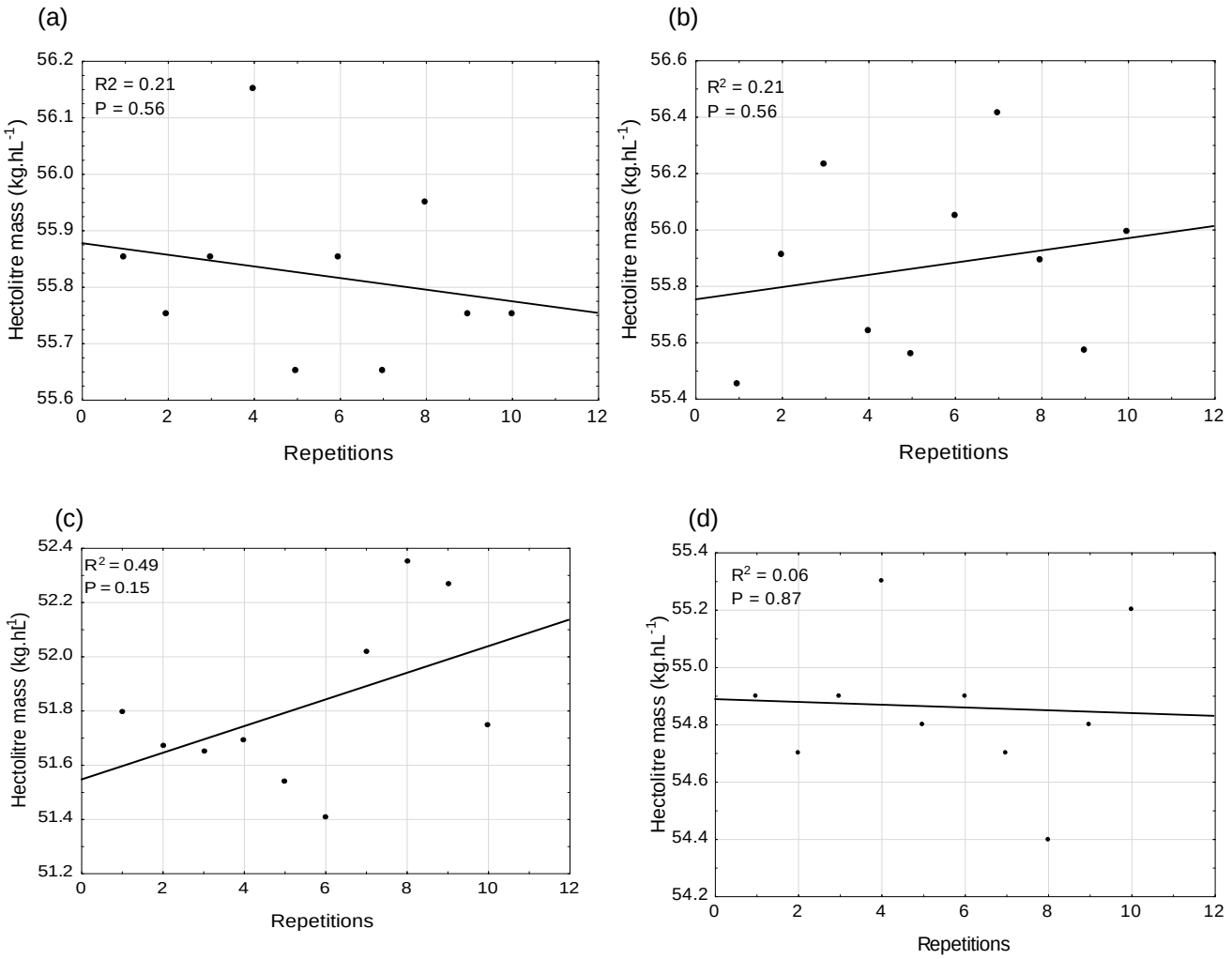

Figure 8 Regression scatter plots showing the differences in hectolitre mass (HLM) values of the ten successive measurements obtained with (a) the South African device using sample 1; (b) the South African device using sample 2; (c) the German device using sample 1; and (d) the German device using sample 3.

Average HLM measurements for the three respective oat samples as determined for each device are illustrated in **Fig. 9**. Again the SA and North American devices resulted in significant lower (P<0.05) HLM values; this was irrespective of the sample used. **Fig. 10** shows the difference between the average HLM values obtained from the three oat samples combined with repeated analysis of variance (RANOVA). Significant differences (P<0.05) were observed between most of the devices. This was however, due to a single work sample being used resulting in very little variation within each sample. These small differences also indicate high repeatability within each of these devices. Thus, if the same sample is analysed repeatedly the same result is obtained. Distinctly lower average HLM values were obtained with the South African and North American devices.

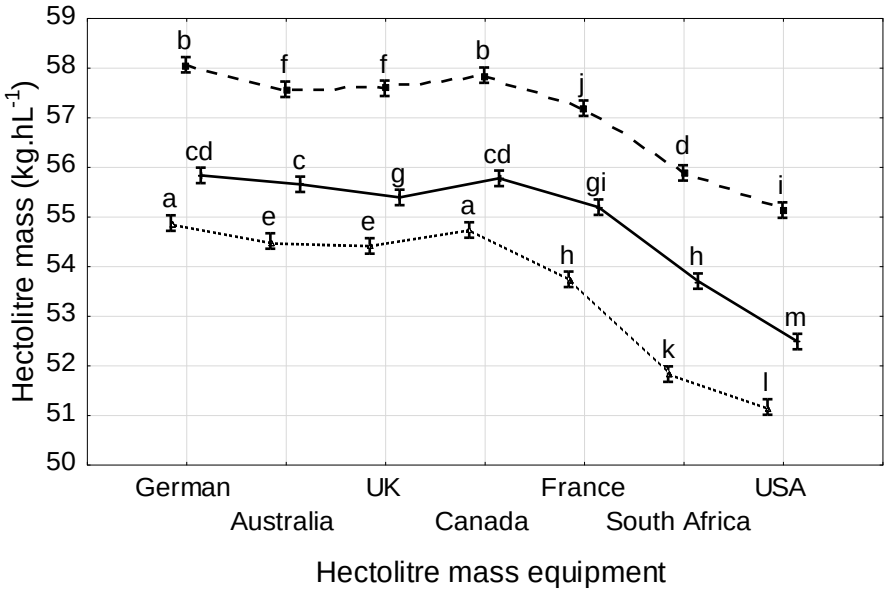

Figure 9 Differences between the average hectolitre mass (HLM) values of the three oat samples respectively, obtained with the respective HLM devices, as determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

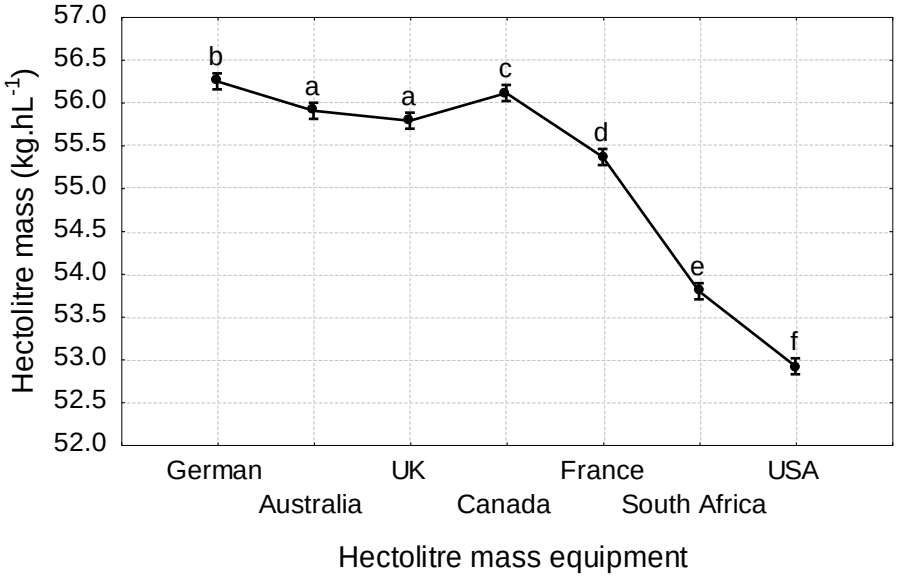

Figure 10 Differences between the average hectolitre mass (HLM) values, obtained for the three oat samples combined, as determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

The average ICC agreement and ICC consistency values are shown in **Table 3**. Similar average ICC agreement results were obtained for the German, UK, Canadian, French and Australian devices. The low values of approximate 0.7 would have been due to the significant differences obtained due to single work samples being used. The SA and North American devices had much lower average ICC agreement values of 0.56 and 0.43, indicating a substantial difference in actual values compared to the other devices. In spite of the devices producing different actual HLM values, they were highly correlated with ICC consistency values of more than/and or equal to 0.94.

The differences in the values observed between the devices could also be attributed to the different operating procedures of the devices and the different volumes of the receiving cups or receptacles. The German device is equipped with a 1 litre measuring cup whereas the South African device has a 500 mL. It is also believed that variation between the instruments and operator errors in measurement can arise from the manner in which the grain is poured into the measuring container and the manner in which the grain packs into the measuring container. During the measurements, any vibration, shaking or knocking of the instrument were avoided even though it could not be hundred percent controlled.

Table 3 Intra-class correlation (ICC) agreement and ICC consistency for the respective hectolitre mass (HLM) devices

HLM equipment	Average ICC agreement	Average ICC consistency
German	0.72	0.96
Australia	0.75	0.94
UK	0.76	0.95
Canada	0.73	0.95
France	0.76	0.97
SA	0.56	0.94
USA	0.43	0.96

Experiment 3: Comparison of the HLM devices using a single work sample of oat samples

No significant difference ($P>0.05$) were observed between the three sub-samples obtained (**Fig. 11**). This indicates that obtaining the sub-samples, using the Boerner divider was done efficiently and that the three sub-samples were representative of the respective bulk oat samples. **Fig. 12** shows comparison of the HLM devices for the average measurements. As before the, SA and North American device resulted in significantly lower HLM values. Although the UK and French devices also differed significantly, it would not have any practical impact. The reason again, due to single work samples being used (almost no variation within the sample), even very small differences were shown as being significant.

The differences in actual average HLM values as obtained with the respective devices have also been evaluated by means of the ICC agreement and ICC consistency (**Table 4)**. An average ICC agreement of 0.88 and ICC consistency of 0.99 were obtained. Thus, although actual differences between the devices have been observed, the results obtained with the devices are highly correlated. **Table 4** also shows the individual results between the respective devices, which clearly shows the SA device resulting in HLM values distinctly different to the other devices (apart from the USA device).

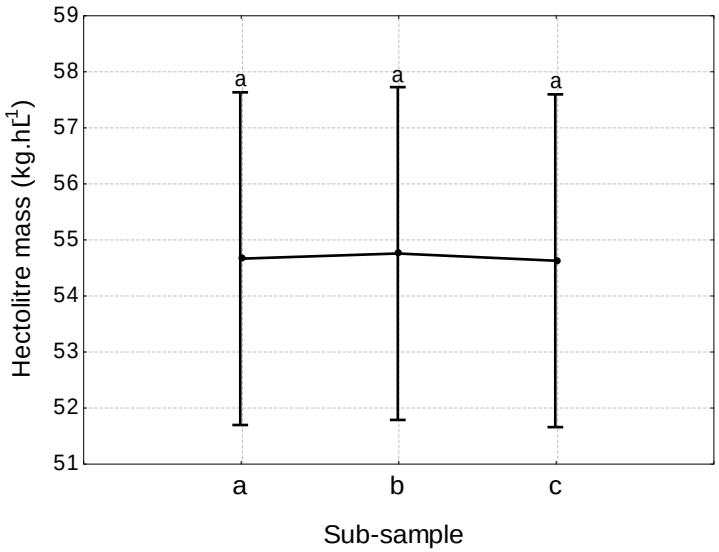

Figure 11 Differences between the average hectolitre mass (HLM) values, obtained for the three sub-samples taken for the ten oat samples using single work samples, as determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

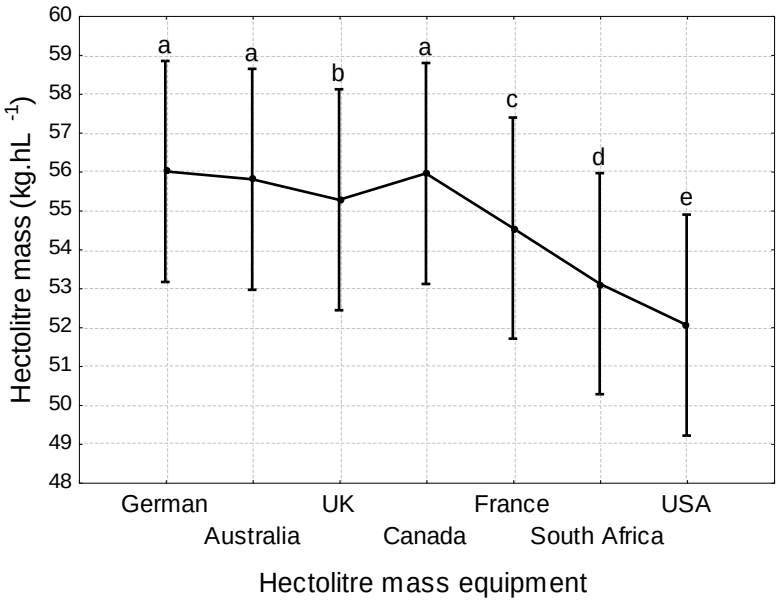

Figure 12 Differences between the average hectolitre mass (HLM) values, obtained for the ten oat samples using single work samples, as determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

Table 5 Intra-class correlation (ICC) agreement and ICC consistency between the (HLM) values as determined on the HLM devices using ten single work oat samples

HLM equipment		ICC agreement	ICC consistency
German	Australia	0.99	0.99
German	UK	0.98	1.00
German	Canada	0.99	0.99
German	France	0.94	0.99
German	SA	0.81	0.99
German	USA	0.70	0.99
Australia	UK	0.98	0.99
Australia	Canada	0.97	0.97
Australia	France	0.94	0.97
Australia	SA	0.82	0.97
Australia	USA	0.71	0.98
UK	Canada	0.98	0.99
UK	France	0.97	0.98
UK	SA	0.88	0.99
UK	USA	0.78	0.99
Canada	France	0.94	0.99
Canada	SA	0.81	0.99
Canada	USA	0.70	1.00
France	SA	0.94	1.00
France	USA	0.85	1.00
SA	USA	0.97	1.00
Overall		**0.88**	**0.99**

Experiment 4: Comparison between two German and two South HLM devices using oat sub-samples

As expected, the two German devices resulted in similar HLM values (P>0.05). Similarly, the two South African devices did not differ significantly (P>0.05) (**Fig. 13**). The average HLM value of the Germany devices was higher (3.12 $kg.hL^{-1}$) than that of the South African devices (**Fig. 14**). The average HLM values of ten repetitions for all four devices **Fig. 15**. This shows good within instrument repeatability with only one measurement being significantly (P<0.05) lower.

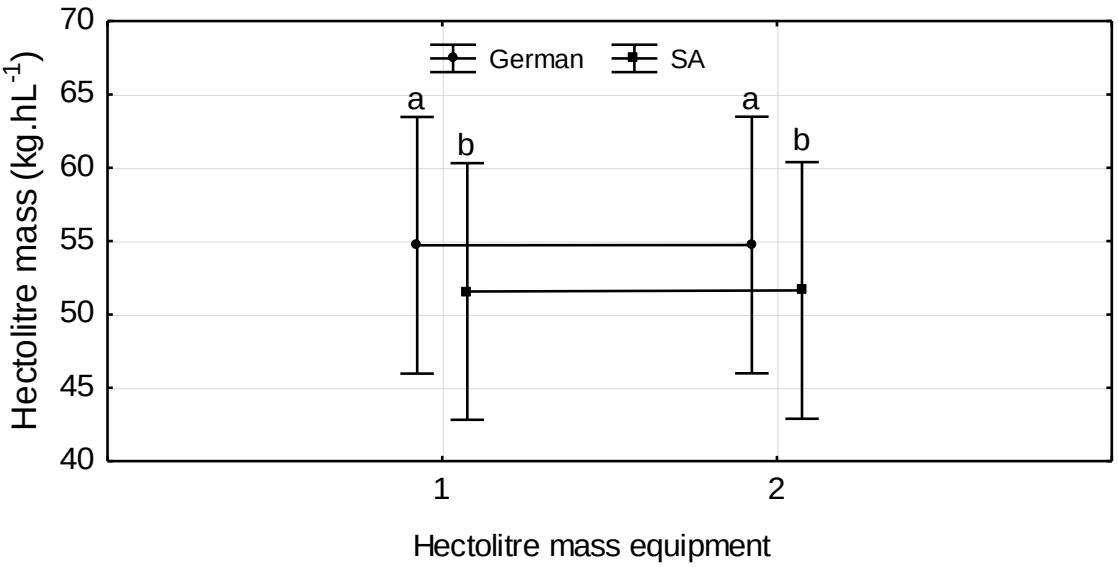

Figure 13 Differences between the average hectolitre mass (HLM) values, obtained with two German (German 1 & German 2) and two South African devices (SA 1 & SA 2) as determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Error bars denote 0.95 confidence intervals.

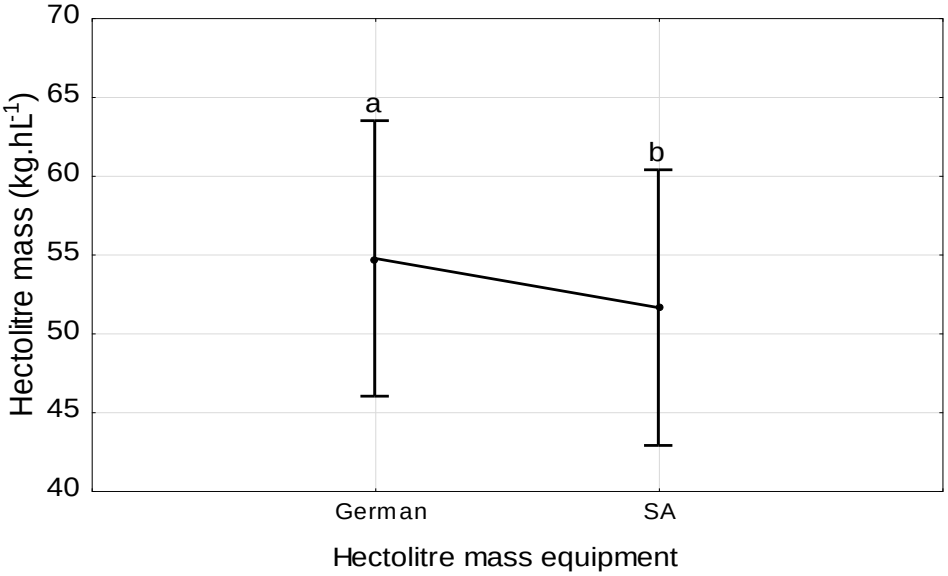

Figure 14 Difference in average hectolitre mass (HLM) values, between the German and the South African HLM devices, determined with repeated analysis of variance (RANOVA). Different letters indicates significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

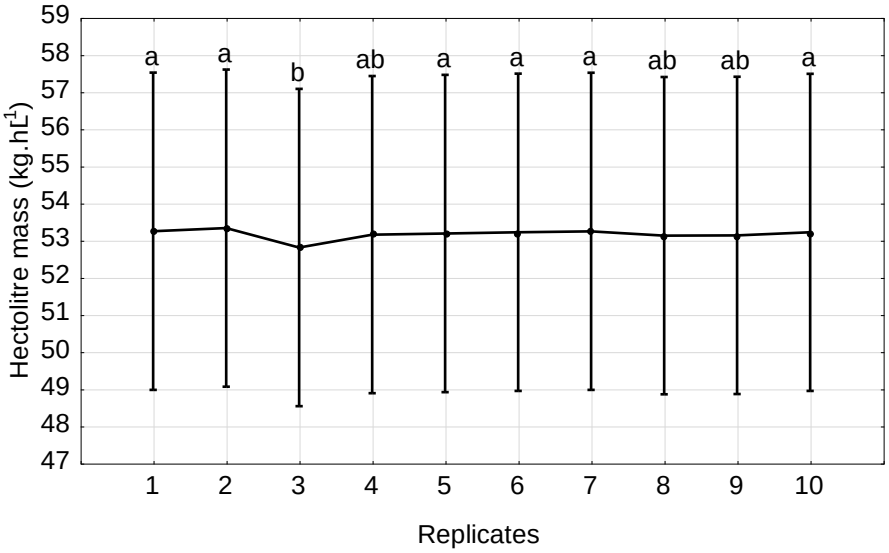

Figure 15 Differences between the combined average hectolitre mass (HLM) values, of ten repetitions obtained for all four devices (two Germany & two South African), determined by repeated analysis of variance (RANOVA). Different letters indicates significant differences between repetitions obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars indicate 0.95 confidence intervals.

Experiment 5: The effect of rubbing of the oat on its HLM values using sub-samples

From the RANOVA results (**Figs. 16 & 17**), it was clear that the average HLM values significantly increased ($P<0.05$) when samples were rubbed before HLM measurements were performed. Similar to results from earlier experiments, both the South African and North American device produced significantly lower ($P<0.05$) average HLM values compared to other devices.

The significant increase in average HLM values when samples are rubbed could be due to changes in shape and size the oat grains undergo upon rubbing. The HLM of oat could be significantly increased by mechanically rubbing, clipping off the tips of oat grains and polishing the oat grains. The reason being that oat with tippy hulls or awns has more air space between them. Thus clipping off the tips; rubbing or polishing would decrease empty spaces within the oat grain and act to improve packing efficiency and HLM of oat grains.

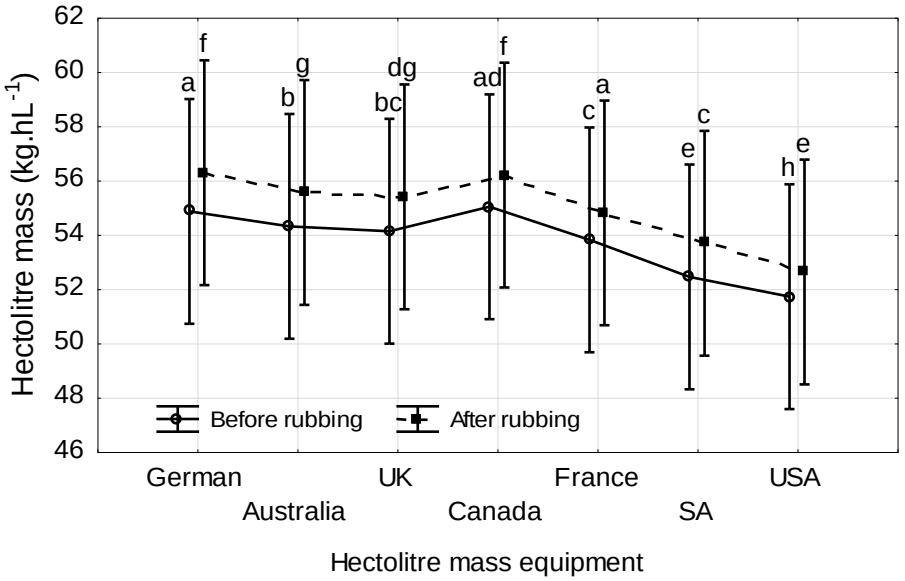

Figure 16 Differences between the average (HLM) values, of the three oat samples before and after rubbing, determined with repeated analysis of variance (RANOVA). Different letters indicates significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

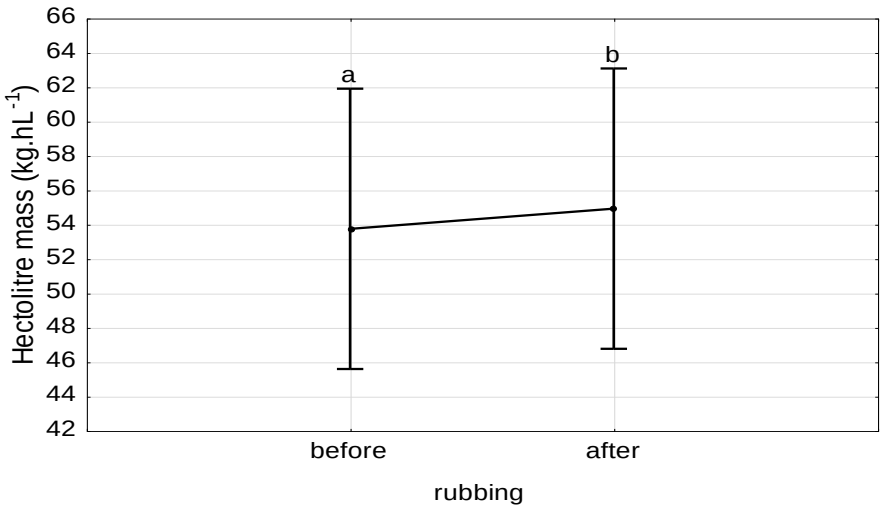

Figure 17 Differences between the combined average hectolitre mass (HLM) values, of the oat samples before and after rubbing, determined with repeated analysis of variance (RANOVA). Different letters indicate significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals

Experiment 6: Effect of consecutive wetting and drying of oat samples on HLM results

The HLM values decreased significantly (P<0.05) from 53.79 to 47.62 kg.hL^{-1} when the moisture content increased from *ca*. 10 to 18% (**Fig. 18)**. The HLM values of the control samples (which did not receive any treatment before drying) increased slightly, although not significant, after being dried to *ca*. 10%. When these samples were conditioned back to their original moisture contents after drying, their HLM value decreased slightly below the HLM value obtained at its initial moisture content. This would have been expected since these changes in moisture content were really small. Similarly the HLM

values of samples of which the moisture contents were increased to 14% did not change significantly after been dried and conditioned again. In contrast the samples which were conditioned to *ca.* 16 and 18% moisture contents, dried to *ca*. 10% and conditioned to *ca*. 16% again did result in significantly lower (P<0.05) HLM values after the second conditioning. Thus, the greater the change in moisture, the more the severe the resulted effect on the HLM measurement of oats. This can clearly be seen in **Fig. 19**.

The decrease in HLM values observed after the second wetting could be due to the swelling and roughening of the hulls of the oat grains. Also during hydration of the grains, it expands resulting in lesser kernels required to fill the test container. The expanded kernels, however, do not contract to their orginal size on drying. Their bran layer and hulls get loosened and the exterior structure of the kernels are disturbed.

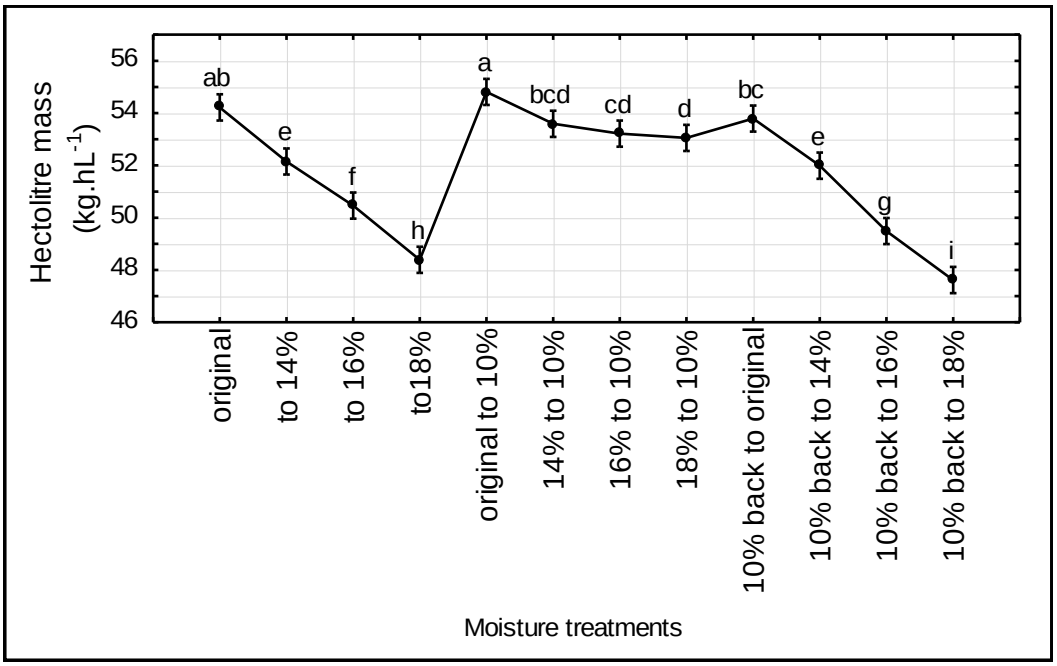

Figure 18 Effect of moisture content on the average hectolitre mass (HLM) values, measured after consecutive wetting and drying cycles of oat samples, determined with repeated analysis of variance (RANOVA). Different letters indicates significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

Differences in average HLM values, obtained by the respective HLM devices, when samples where analysed at different moisture contents are shown **Figs. 20** and **21**. As was observed in earlier experiments the South African and North American devices resulted in the lowest HLM values.

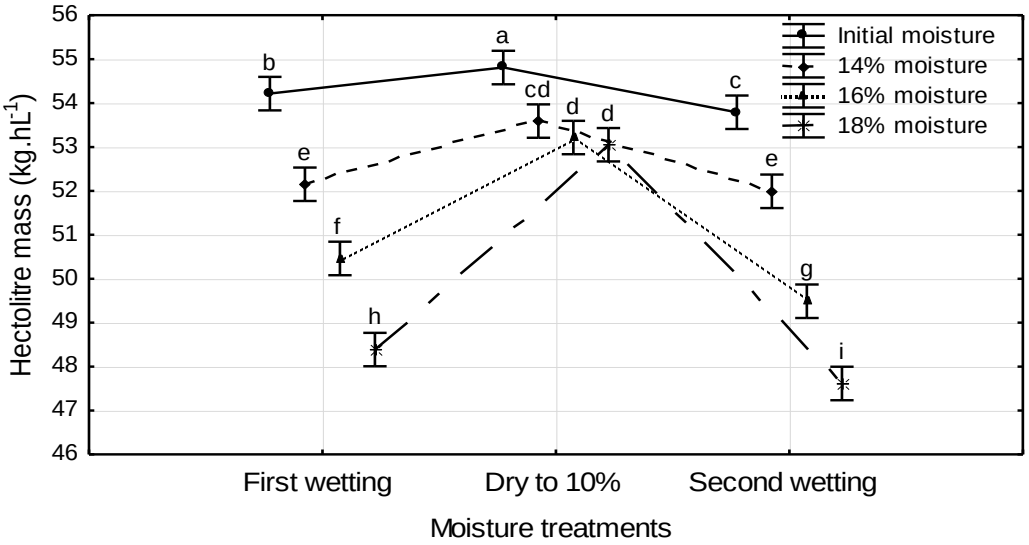

Figure 19 Differences in average hectolitre mass (HLM) values, after wetting (1st & 2nd wetting) and drying cycles, determined with repeated analysis of variance (RANOVA). Different letters indicates significant differences obtained from Fischer least significant difference (LSD) post-hoc analyses. Vertical bars denote 0.95 confidence intervals.

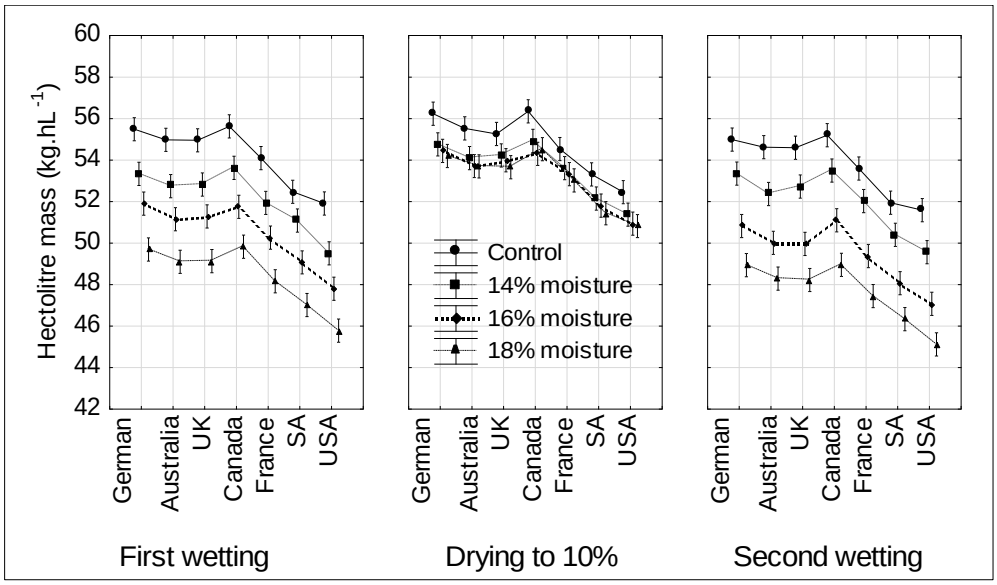

Figure 20 Differences in average hectolitre mass (HLM) values, of samples that have undergone wetting and drying cycles, Error bars denote 0.95 confidence intervals.

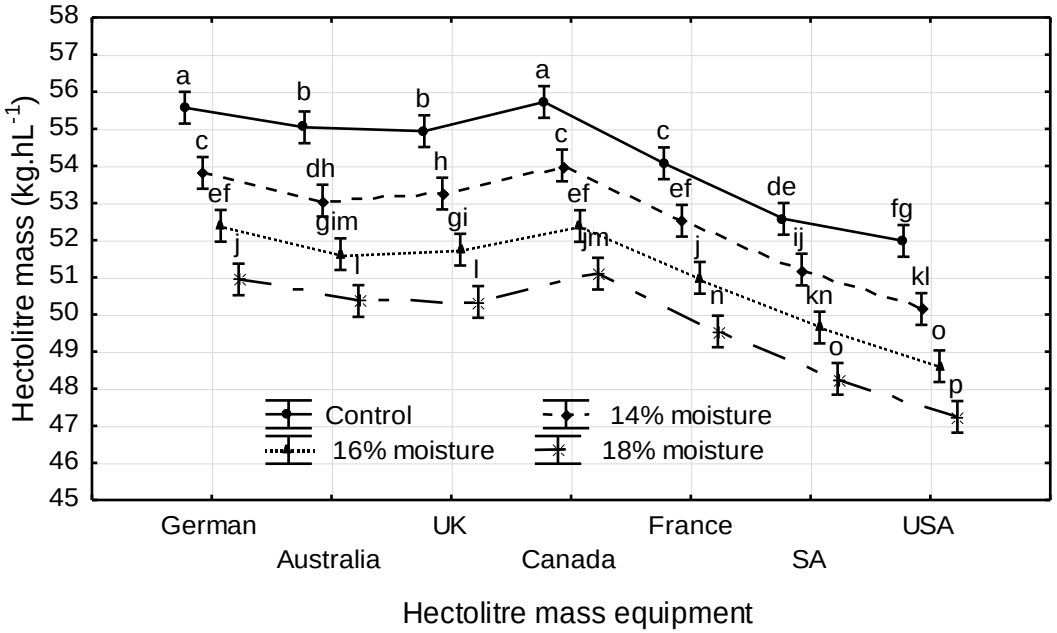

Figure 21 Differences in average hectolitre mass (HLM) obtained for all the HLM devices when samples were conditioned to different moisture levels (*ca*. 14, 16 & 18%). Different letters indicate significant differences between devices determined with Fischer least significant difference (LSD) post-hoc analyses. Error bars denote 0.95 confidence intervals.

Conclusion and recommendation

As was expected based on earlier research being performed on HLM devices from different countries using wheat and maize, the South African device resulted in significantly lower HLM values compared to the majority of the other devices. The high ICC consistency values, however, confirmed the high correlation between results obtained. It would thus be feasible to replace the SA device with an alternative device such as the German device. The significant increase in HLM values when oat samples are rubbed before the measurement is performed was confirmed. Consecutive wetting and drying cycles had a significant effect on the HLM determinations of oats. Experiments thus far have only been performed on mixed oat samples due to difficulties to get hold of pure oat samples.

Acknowledgments

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Appendices – Raw data of experiments

Experiment 1: Variation between HLM devices using sub-samples

HLM values for the 10 repetitions as performed on each device using one oat sample.

German	Australia	UK	Canada	France	SA	USA
53.60	53.01	53.37	53.80	52.57	52.15	51.20
53.10	53.32	53.92	53.40	52.56	52.59	51.07
52.60	52.96	52.54	53.60	52.87	51.37	50.68
53.20	53.21	53.02	53.40	53.42	51.06	51.42
53.5o	52.61	53.6	53.40	53.72	51.14	50.20
53.80	53.66	52.02	53.80	53.43	51.30	51.16
52.50	52.64	53.89	53.80	52.94	51.94	51.15
53.60	53.39	53.27	52.20	52.95	51.17	50.38
53.70	53.54	53.52	51.60	53.69	51.88	50.55
53.90	53.54	52.10	53.20	53.27	52.14	51.29

Experiment 2: Variation in repeatability within and variation between the HLM devices using single work samples

Table 2 HLM values for 10 repetitions on each HLM device using single work samples of three oat samples.

Sample	German	Australia	UK	Canada	France	SA	USA
1	54.9	54.26	54.02	54.4	53.69	51.8	51.01
1	54.7	54.11	54.67	54.6	53.65	51.67	51.15
1	54.9	55.03	54.72	54.4	53.56	51.65	51.36
1	55.3	54.31	54.06	55.2	53.8	51.69	51.15
1	54.8	54.56	54.77	54.8	53.75	51.54	51.67
1	54.9	54.44	54.48	54.6	53.78	51.41	50.95
1	54.7	54.61	54.49	54.4	53.81	52.02	51.15
1	54.4	54.53	54.6	54.8	53.7	52.35	50.97
1	54.8	54.31	54.31	55.4	53.76	52.27	51.23
1	55.2	54.83	53.87	54.6	53.76	51.75	50.89
2	57.85	57.69	57.61	57.9	57	55.45	55.07
2	57.85	57.78	57.49	57.5	57.2	55.91	55.23
2	57.95	57.92	57.57	57.9	57.12	56.23	54.96
2	57.95	57.99	56.98	57.9	57.09	55.64	54.96
2	58.25	57.54	57.74	57.5	57.27	55.56	55.49
2	57.95	57.38	57.47	57.7	57.24	56.05	55.1
2	58.25	57.39	57.48	58.3	57.31	56.41	55.24
2	57.95	57.76	57.63	57.5	57.08	55.89	54.98
2	58.25	57.02	57.92	57.9	57.23	55.57	55.15
2	58.25	57.1	57.87	58.3	57.2	55.99	55.03
3	55.85	55.49	55.47	55.2	55.02	53.73	52.25
3	55.75	56.13	55.18	55.7	55	53.79	52.57
3	55.85	55.79	55.54	55.4	55.31	53.53	52.55
3	56.15	55.37	55.45	56.1	55.31	53.58	52.55
3	55.65	55.15	55.24	55.9	55.39	53.86	52.43
3	55.85	55.73	55.08	55.9	55.07	53.3	52.33
3	55.65	55.5	55.7	55.6	55.24	53.67	52.48
3	55.95	55.84	55.09	55.6	55.26	53.44	52.66
3	55.75	55.88	55.62	56.3	55.03	53.89	52.36
3	55.75	55.53	55.38	55.9	55.16	54.11	52.54

Table 3 Intra-class correlation (ICC) agreement and (ICC) consistency between the HLM devices using the three oat samples for Experiment 2

HLM equipment		ICC agreement	ICC consistency
German	Australia	0.93	0.96
German	UK	0.92	0.97
German	Canada	0.97	0.97
German	France	0.82	0.98
German	SA	0.41	0.93
German	USA	0.29	0.97
Australia	UK	0.94	0.94
Australia	Canada	0.92	0.93
Australia	France	0.89	0.96
Australia	SA	0.47	0.92
Australia	USA	0.32	0.94
UK	Canada	0.93	0.95
UK	France	0.93	0.97
UK	SA	0.51	0.93
UK	USA	0.35	0.96
Canada	France	0.85	0.97
Canada	SA	0.44	0.94
Canada	USA	0.3	0.95
France	SA	0.65	0.97
France	USA	0.44	0.98
SA	USA	0.86	0.97
Overall		**0.54**	**0.95**

Experiment 3: Comparison of the HLM devices using a single work sample of oat samples

Table 4 HLM values for the duplicate measurements on each sub-sample using single work samples of 10 oat samples.

Sample	Sub-	Rep	German	Australia	UK	Canada	France	SA	USA
1	a	1	49.35	50.44	47.78	48.6	47.25	45.6	45.31
1	a	2	49.35	51.25	48.22	49.2	47.25	46.06	44.91
1	b	1	49.35	49.72	49.2	49	47.39	46.47	45.16
1	b	2	49.45	50.24	49.13	48.8	47.41	45.95	45.4
1	c	1	48.75	48.56	48.33	48.6	47.2	45.84	45.08
1	c	2	48.75	50.03	48.36	48.6	47.08	45.66	44.89
2	a	1	59.4	58.86	59.16	59.1	57.85	55.85	55.45
2	a	2	59.7	59.25	59.34	60.1	57.6	56.54	55.26
2	b	1	59.2	59.14	59.16	60.5	57.75	56.37	55.07
2	b	2	59.5	59.4	58.61	59.7	57.74	56.5	55.31
2	c	1	58.95	58.32	58.84	58.9	57.62	55.91	55.12
2	c	2	58.95	58.65	58.25	59.3	57.55	56.16	54.94
3	a	1	57.65	58.19	56.12	56.1	55.47	53.69	53.17
3	a	2	57.45	58.15	56.99	56.7	55.74	54.04	53.1
3	b	1	57.55	58.5	57.03	57.1	55.98	54.58	53.16
3	b	2	57.85	58.47	56.78	56.1	56.16	54.14	53.32
3	c	1	57.35	58.23	57.43	57.3	55.63	54	53.42
3	c	2	57.75	57.29	56.39	57.5	55.33	54.32	53.33
4	a	1	55.65	55.95	55.42	56.3	54.91	52.98	52.17
4	a	2	55.75	55.77	54.93	56.3	54.56	53.89	52.26
4	b	1	56.45	55.29	56.05	55.9	54.99	53.6	52.63
4	b	2	56.55	56.27	55.93	57.1	54.63	53.17	52.66
4	c	1	56.05	56.6	55.84	56.3	54.64	53.28	52.38
4	c	2	56.25	56.97	55.36	56.1	54.87	53.51	52.52
5	a	1	50.75	51.06	49.92	52.2	48.96	48	47.11
5	a	2	50.75	50.12	50.33	50.8	49.25	48.53	47.02
5	b	1	50.95	50.05	51.21	51.2	49.82	48.82	47.35
5	b	2	51.25	50.87	50.89	52	49.75	48.58	47.61
5	c	1	50.95	50.76	49.92	50.4	49.48	48.71	47.49
5	c	2	50.55	49.92	49.76	52	49.67	48.12	47.26
6	a	1	58.45	58.04	57.28	58.5	57.35	56.56	55.06
6	a	2	59.05	58.44	57.31	59.3	57.79	56.07	55.48
6	b	1	58.85	58.34	57.81	58.3	57.29	56.14	54.53
6	b	2	58.85	58.27	57.69	57.7	57.37	56.69	54.22
6	c	1	58.95	58.45	57.42	57.9	57.5	55.58	54.23
6	c	2	58.95	58.25	57.67	57.9	57.19	56.16	54.38
7	a	1	60.5	60.21	60.47	60.7	58.87	57.53	56.51
7	a	2	60.7	59.27	60.05	60.7	58.83	57.51	56.48

7	b	1	60.6	60.65	59.44	60.1	58.75	57.43	56.44
7	b	2	60.4	60.22	59.64	60.7	58.76	57.7	56.29
7	c	1	60.2	60.4	59.72	59.9	58.7	57.15	56.23
7	c	2	60.2	60.3	59.72	60.1	58.72	57.09	56.31
8	a	1	58.15	58.16	57.24	57.1	57.01	54.89	53.92
8	a	2	58.55	58.12	56.98	57.7	56.7	54.67	53.96
8	b	1	58.35	57.44	57.44	56.9	56.73	54.83	53.91
8	b	2	58.55	57.66	57.56	57.5	56.83	55.05	54.16
8	c	1	58.05	57.38	57.39	57.9	56.47	54.73	53.96
8	c	2	58.45	57.93	57.42	58.3	56.48	54.98	53.81
9	a	1	60.1	59.86	59.86	60.7	58.68	56.78	56.43
9	a	2	60.2	59.26	59.72	60.5	58.65	56.91	56.34
9	b	1	60.3	59.8	60.07	61.1	58.1	57.38	56.09
9	b	2	60.7	59.76	59.99	61.1	58.94	57.88	56.29
9	c	1	60.8	60.21	60.25	60.7	58.99	58.14	56.86
9	c	2	60.8	60.31	60.46	60.7	59.15	58.4	56.77
10	a	1	48.65	49.37	47.09	49.8	49.07	46.75	46.04
10	a	2	49.85	47.34	48.1	49.6	49	46.4	45.51
10	b	1	48.35	47.48	47.86	49.28	48.43	47.56	45.48
10	b	2	48.45	47.2	48.22	49.2	48.56	47.48	45.88
10	c	1	48.65	49.28	47.37	49.6	47.8	46.6	45.59
10	c	2	48.75	47.72	47.94	49.2	49.97	46.51	45.58

Experiment 4: Comparison between two German and two South HLM devices using oat sub-samples

Table 5 HLM measurements for the 10 repetitions on each of the three samples before and after rubbing, respectively.

Sample	German 1	German 2	SA 1	SA 2
1	54.90	54.50	50.06	52.37
1	54.80	54.70	51.70	52.22
1	54.10	54.80	51.67	50.58
1	55.00	54.70	50.68	51.38
1	54.80	55.20	51.82	50.57
1	55.10	55.20	51.58	51.83
1	55.20	54.80	51.26	51.28
1	54.80	54.90	50.19	51.85
1	54.70	54.80	50.94	51.94
1	54.40	55.00	52.28	51.10
2	51.35	51.35	48.85	48.36
2	50.75	50.95	48.89	48.55
2	51.35	51.15	46.90	47.19
2	51.25	50.95	48.54	48.73
2	50.85	51.15	48.53	47.87
2	51.45	51.35	47.55	48.31
2	51.80	51.45	48.07	48.18
2	51.60	51.05	48.29	47.91
2	50.95	51.35	48.35	47.75
2	51.05	51.25	48.00	48.29
3	58.25	58.25	55.19	55.52
3	58.25	58.25	55.55	55.36
3	57.65	57.65	55.03	55.64
3	57.85	57.85	55.44	55.48
3	58.65	58.65	55.52	54.62
3	58.05	58.05	55.13	55.00
3	58.15	58.15	55.31	55.28
3	58.25	58.25	54.98	55.47
3	58.05	58.05	55.39	55.33
3	58.25	58.25	55.38	55.34

Experiment 5: The effect of rubbing of the oat on its HLM values using sub-samples

Table 6 HLM measurements for the 10 repetitions on each of the three samples before and after rubbing respectively.

			HLM before rubbing				
sample	**German**	**Australia**	**UK**	**Canada**	**France**	**SA**	**USA**
1	56.25	56.38	56.27	56.5	55.71	54.17	53.44
1	56.25	55.89	56.95	56.1	55.14	53.89	53.28
1	56.25	55.52	56.35	56.5	55.41	54.48	53.97
1	56.45	56.63	55.75	56.5	55.02	53.85	53.87
1	56.25	55.62	56.15	55.9	55.05	53.62	53.92
1	56.65	56.22	55	56.5	55.73	54.42	53.79
1	56.15	56.07	55.21	56.3	55.58	53.66	53.6
1	56.05	56.16	55.36	56.5	55.8	53.75	53.4
1	56.15	55.11	56.12	56.1	55.5	53.83	53.27
1	56.15	56.46	55.99	56.9	55.48	53.47	53.78
2	51.15	50.95	50.17	51.4	50.01	47.91	48.15
2	51.15	51.8	49.55	51.6	50.01	48.06	47.68
2	51.05	50.31	50.47	51.4	50.04	48.56	47.86
2	51.05	50.82	50.53	51.8	50.01	48.69	48.33
2	51.25	49.44	49.68	51.4	49.88	48.27	48.03
2	51.6	50.4	49.89	51.6	49.64	48.66	48.22
2	51.45	50.55	50.35	51.4	49.92	48.49	47.91
2	51.25	50.06	50.44	51.8	49.84	48.65	47.98
2	51.25	50.58	49.9	51.8	49.99	48.96	48.05
2	51.15	50.89	49.69	51.8	49.89	48.59	48.12
3	57.05	56.49	56.45	57.3	55.74	54.87	53.41
3	57.05	56.63	56.29	57.1	56.05	54.98	53.21
3	57.05	56.25	56.65	57.3	55.02	54.46	53.47
3	57.15	56.58	56.52	56.7	56.2	54.7	53.78
3	57.45	56.04	55.61	57.5	56.16	54.63	53.83
3	57.05	56.06	55.63	56.5	56.16	55.83	53.64
3	56.95	56.15	56.64	57.1	56.34	55.02	53.36
3	56.95	56.39	56.77	57.5	56.06	55.27	53.21
3	57.05	56.43	56.7	56.1	56.38	54.91	53.27
3	56.85	56.06	56.51	57.7	56.26	54.48	53.46
			HLM after rubbing				
Sample	**German**	**Australia**	**UK**	**Canada**	**France**	**SA**	**USA**
1	58.25	57.28	57.84	58.3	56.01	54.5	54.57
1	58.05	57.28	57.46	58.1	56.23	55.01	54.12
1	57.65	57.16	57.32	57.7	56.84	54.78	54.34
1	58.75	57.39	56.91	57.9	56	54.68	54.34
1	58.05	57.83	57.51	58.5	56.48	54.7	54.43
1	57.85	58.53	57.78	57.7	56.08	54.95	54.46

1	57.55	57.01	57.67	57.7	56.67	55.01	54.37
1	58.35	57.12	57.64	58.3	56.18	54.89	54.39
1	57.85	57.73	57.48	58.3	56.32	55.51	54.16
1	57.95	58.27	57.14	57.7	56.35	55.3	54.41
2	52.4	52.44	51.51	52.6	51.33	49.8	48.89
2	52.5	51.78	51.21	52.8	51.24	49.82	49.13
2	52.4	51.27	51.19	52.4	51.31	49.74	49.14
2	52.2	51.15	51.23	52.4	51.04	49.69	48.92
2	52.1	51.32	51.14	52.8	51.02	49.84	48.84
2	52.4	51.43	51.45	52.6	50.88	49.96	48.94
2	52.5	51.45	51.26	52	50.61	50.68	48.99
2	52.3	51.8	51.37	52.6	50.85	50.47	48.86
2	52.2	51.64	51.2	52.2	51.37	50.19	49.05
2	52.3	51.95	51.28	52.4	50.84	50.8	49.1
3	58.75	57.56	57.65	58.5	56.94	55.75	54.2
3	58.85	57.22	57.74	58.1	56.95	55.87	54.25
3	58.45	57.5	57.84	58.1	56.82	56.09	54.77
3	58.05	57.51	57.17	57.9	56.8	56.55	54.33
3	58.25	57.43	57.14	57.7	56.98	55.63	54.54
3	58.85	58.64	57.2	57.7	57.32	56.27	54.77
3	58.65	57.43	57.19	57.7	56.98	55.82	54.63
3	58.25	57.09	57.7	58.3	57.21	55.92	54.3
3	58.15	57.15	57.47	58.1	57.1	56.26	54.69
3	58.45	57.05	56.92	58.5	57.11	55.76	54.52

Experiment 6: Effect of consecutive wetting and drying of oat samples on HLM results

Table 7 HLM values after consecutive wetting and drying of oat samples

Sample	Moisture	Rep.	German	Australia	UK	Canada	France	SA	USA
Original moisture content									
1	11.5	1	59.9	59.83	59.89	60.1	58.58	57.23	56.34
		2	60.2	59.29	59.43	60.3	58.73	57.04	56.43
2	10.8	1	56.95	56.39	56.82	57.9	55.81	53.98	53.09
		2	57.65	56.8	56.02	56.7	55.59	53.37	53.32
3	11.3	1	48.65	48.8	48.08	48.4	47.21	45.99	45.23
		2	48.55	47.8	48.1	48.4	47.2	45.7	45.47
4	10.9	1	55.95	55.89	55.97	56.7	54.72	53.74	52.67
		2	56.05	54.99	55.32	56.5	54.92	52.73	52.71
Original to 14% moisture content									
1	13.5	1	58.65	58.68	58.2	58.9	57.05	56.04	54.58
		2	58.65	57.97	58.44	59.3	57.12	56.66	54.46
2	13.7	1	54.40	53.5	53.74	54	53.03	52.1	50.63
		2	54.50	53.93	54.06	54.6	53.18	52.15	50.91
3	13.3	1	47.10	46.7	46.45	47.8	45.69	44.58	43.44
		2	47.30	46.87	46.39	47.4	45.8	44.74	43.39
4	13.9	1	53.10	52.05	53.14	53.2	51.96	51.38	49.52
		2	53.00	52.25	52.14	53.8	51.68	51.03	49.14
Original to 16% moisture content									
1	15.3	1	57.56	57.31	57.4	57.5	56.3	55.62	53.51
		2	57.85	57.27	57.08	57.7	56.44	55.02	53.62
2	15.8	1	52.6	51.87	51.63	52.8	51.05	49.65	48.67
		2	52.8	51.89	52.26	52.6	50.88	49.16	48.54
3	16.1	1	45.4	44.41	44.95	45	43.23	41.97	41.47
		2	45.8	44.3	44.76	45.2	43.46	42.4	41.45
4	15.1	1	51.6	51.29	50.83	51.6	49.95	48.94	47.49
		2	51.6	50.88	51.38	51.6	50.82	49.81	47.66
Original to 18% moisture content									
1	17.6	1	55.3	54.77	54.49	55.9	53.74	52.36	51.33
		2	55.45	55.21	54.52	56.3	53.94	53.16	51.63
2	17	1	50.55	49.81	50.63	50.4	49.07	47.53	46.7
		2	50.65	49.69	50.4	50	48.97	47.61	46.73
3	16.9	1	43.05	42.66	42.83	43	41.74	40.58	39.02
		2	43.25	42.37	42.52	43	41.68	40.38	39.29
4	17.5	1	49.55	49.26	48.96	50	48.33	46.72	45.6
		2	49.75	49.03	48.72	50	47.81	47.81	45.98

Table 7 continued…

Sample	Moisture	Rep.	German	Australia	UK	Canada	France	SA	USA
			Original moisture content to 10% moisture content						
1	9.7	1	60.6	60.23	59.98	60.9	58.96	57.68	57.26
		2	60.8	59.99	59.87	60.7	58.91	57.94	56.79
2	9.4	1	57.65	56.94	56.29	58.1	55.83	54.01	53.26
		2	57.85	56.49	56.84	57.9	55.89	54.36	53.45
3	10.1	1	49.75	49.25	48.95	49.9	48.56	47.78	46.43
		2	49.95	49.09	48.73	49.8	48.39	47.33	46.82
4	10.2	1	56.82	55.99	56.02	56.9	54.75	53.82	52.85
		2	56.45	56.27	55.41	56.6	54.96	53.55	52.77
			14% moisture content to 10% moisture content						
1	9.2	1	58.95	58.05	58.86	59.5	58.32	56.82	56.09
		2	59.3	58.53	58.56	58.9	58.23	57.32	55.78
2	9.8	1	55.75	54.83	54.81	55.4	54.14	52.79	51.89
		2	55.85	55.09	55.19	55.6	54.22	53.05	51.9
3	9.8	1	48.95	48.5	48.89	49.4	48.1	46.3	45.89
		2	49.15	48.37	48.71	49.8	47.87	46.05	45.86
4	9.7	1	55	54.32	54.53	55.2	54.08	52.11	51.91
		2	55.1	55.06	54.26	55.6	53.93	52.72	51.66
			16% moisture content to 10% moisture content						
1	10.1	1	59.3	58.7	58.02	59.5	58.11	56.38	55.6
		2	59.05	58.49	58.38	59.1	57.9	57.1	55.44
2	9.9	1	55.85	54.38	55.53	55.2	54.35	51.98	51.67
		2	55.95	54.89	55.3	55.4	54.44	52.17	51.6
3	10.2	1	48.35	47.76	48.26	48.2	47.49	45.96	45.2
		2	48.45	47.72	48.27	48.6	47.34	46.09	45.37
4	10.2	1	54.3	53.73	53.88	54	53.53	52.71	51.23
		2	54.3	54.03	54.28	54.4	53.42	52.06	51.39
			18% moisture content to 10% moisture content						
1	10.9	1	58.75	58.8	57.93	59.1	57.62	55.92	55.6
		2	58.55	57.88	58.42	58.9	57.61	56.02	55.31
2	9.8	1	55.1	54.43	54.72	55	53.89	51.82	51.34
		2	55.2	54.25	53.84	54.8	53.66	51.90	51.17
3	10.6	1	48.55	47.95	47.82	49	47.46	46.07	45.09
		2	49.05	47.59	47.98	49.2	47.45	46.06	45.14
4	9.9	1	54.2	54.99	54.39	55.2	53.32	51.73	51.39
		2	54.2	53.69	54.18	55	53.15	51.99	51.52

Table 7 continued…

Sample	Moisture	Rep.	German	Australia	UK	Canada	France	SA	USA
			10% moisture content to original moisture content						
1	11.2	1	59.8	59.03	59.36	59.9	58.17	56.97	55.93
		2	56.7	59.29	58.91	59.5	58.1	56.95	56.09
2	10.4	1	56.95	56.2	55.83	56.7	54.38	53.03	52.68
		2	56.85	55.93	55.54	56.5	54.78	53.38	52.66
3	11.5	1	48.85	48.3	47.98	48.2	47.26	45.69	45.22
		2	48.65	48.01	48.2	48.6	47.13	45.17	45.23
4	10.5	1	56.15	54.92	55.55	56.3	54.52	52.16	52.53
		2	55.95	55.28	55.41	55.9	54.43	52.23	52.37
			10% moisture content to 14% moisture content						
1	14.2	1	58.05	57.48	56.97	58.3	56.6	55.29	54.2
		2	57.75	57.32	56.81	58.3	56.46	55.33	54.21
2	13.8	1	54.4	53.08	54.09	55	53.64	52.44	51.14
		2	54.6	53.49	54.48	54.4	54.02	51.76	51.09
3	13.7	1	47.5	46.36	46.6	47.2	45.48	43.83	43.75
		2	47.5	46.62	46.87	47.4	45.99	44.49	43.43
4	14.4	1	53.5	52.04	53.06	54	52.01	49.95	49.52
		2	53.5	52.53	52.94	53.4	51.99	50.11	49.17
			10% moisture content to 16% moisture content						
1	15.6	1	56.05	56.5	55.49	56.7	55.26	53.8	52.9
		2	56.05	56.03	55.93	57.1	55.45	53.66	52.97
2	15.3	1	51.7	50.23	50.83	51.8	50.25	48.19	47.66
		2	51.8	50.65	50.56	52	50.39	49.15	47.53
3	15.8	1	44.3	43.57	43.26	44.4	42.61	41.38	40.13
		2	44.3	42.98	43.05	44	42.64	41.58	40.49
4	15.2	1	51.15	50.08	50.21	51.4	49.17	48.35	47.49
		2	51.25	50.05	50.35	51.4	49.23	48.44	47.45
			10% moisture content to 18% moisture content						
1	17	1	54	53.9	53.21	54.4	52.51	51.32	50.73
		2	53.9	54.18	53.34	54.8	52.44	51.79	50.44
2	17.4	1	50.15	49.2	49.3	49.6	48.54	47.14	46.02
		2	50.15	48.66	49	50	48.38	46.85	46.07
3	17.2	1	42.35	41.64	41.18	41.8	40.69	39.79	37.92
		2	42.45	41	41.92	42.2	40.95	39.95	38.18
4	17.6	1	49.15	49.28	48.74	49.2	47.93	46.79	45.62
		2	49.35	48.47	49.09	49.6	48.14	47.07	45.97