Application Note SC004: Determining Screening Fractions and Kernel Roundness with Digital Image Analysis

B.G. Armstrong[1], M. Weiss[1, 2], R.I. Grieg[1], J. Dines[3], J. Gooden[1, 4] and G.P. Aldred[1]

[1] Institute of Food and Crop Science, University of Ballarat, Ballarat, VIC, 3353, Australia
[2] Weiss Enterprises, Branford, CT, 06405, USA
3 Allied Mills, Toowoomba, Qld, 4350, Australia
4 Joe White Maltings, Melbourne, VIC, 3000, Australia

INTRODUCTION

Maltsters and millers prefer large, plump (thick) grains. These grains contain a higher percentage of endosperm, which usually means a higher yield of white flour or soluble extract from the grain (Burger and Laberge, 1985). Screening the grain with an array of sieves of diminishing slot widths provides useful information about the sample's size distribution, and hence potential yield. Maltsters also desire a uniform sized grain to produce homogenous malt (Edney, 1996). However, multi-screen gradings can be time-consuming, so rapid Digital Image Analysis (DIA) screening methods would be desirable. It is difficult to estimate the screening gradings accurately with standard DIA systems (Gebhardt, Rasmusson et al. 1993). This is because these systems cannot 'see' the kernel thickness. On a flat surface the seeds display their length and width rather than their thickness. Developing an indented tray to hold some kernels in an "on-edge" position would match the orientation in which they slide through the screens. This would enable direct DIA thickness measurements that could be used to assign each seed to its appropriate screening fraction. This paper presents one attempt to develop such a tray and assesses its usefulness.

Plumpness is typically determined by screening (eg plump barley includes all kernels thicker than 2.5 mm) or occasionally by measuring the kernel width to length ratio by DIA or with callipers (Edney, Bassily and Symons, 1998). Neither of these approaches provides a comprehensive indication of the three-dimensional shape of the kernel.

The novel Roundness parameter, presented later in this paper, provides this information. Roundness is calculated from the seed's thickness, width and length ratios and is a useful indicator of grain shape. Measuring individual kernels with callipers is slow and tedious. DIA, coupled with a bi-modal indented seed tray, can rapidly measure hundreds of kernels at a time. If DIA can accurately measure kernel thickness, it will make roundness measurements readily available kernel quality information. Can this system accurately estimate roundness?

This paper also examines whether a DIA system incorporating an indented tray is capable of accurately estimating the kernel mass and the screening gradings of wheat and barley. Finally, it attempts to establish a link between the DIA determined grain properties and flour/extract yield.

MATERIALS AND METHODS

Indented Tray

Unique indented trays (patent pending) were developed for barley and wheat with sections designed to hold half of the grain sample "on-edge" (in narrow, deep indents holding the kernel so the crease is facing to the side of the indent) and half of the sample laying “flat” (in wide indents with the crease facing up or down). 255 barley kernels from 14 cultivars and 205 wheat seeds from 10 cultivars were individually weighted and measured with digital callipers. The kernels and “flat-edge” tray were scanned using our DIA system (SeedCount) with the seeds first in the narrow and then in the wide section. The seed images were isolated from the tray and digitally analysed. Each seed’s flat and on-edge DIA data was combined to generate a series of multivariate equations that predict each kernel’s thickness, roundness, mass and screenings grouping. These results were compared with the conventional data.

Roundness

Roundness values are calculated using the following dimensionless equation:

Roundness = (Width/Length + Thickness/Length + Thickness/Width)/3

The wheat and barley kernels that had been individually measured were compared to their respective DIA values and a small SeedCount Roundness adjustment equation was generated.

Screenings

The equations were then bulk tested in duplicate on 26 barley and 28 wheat varieties with essentially full trays. The trays can hold up to 658 barley and 1052 wheat kernels. The kernel data from the flat and on-edge sections is digitally combined to form three-dimensional virtual seeds and their adjusted thickness, roundness, mass and screening group is calculated. These predictions were then compared to standard screenings results for the same samples using certified screens (Institute of Brewing (IOB) Method 1.13, 1999).

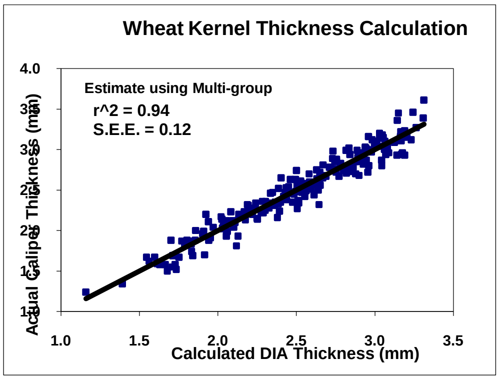
Yield

Roundness, screen gradings, hectoliter weight (HW), Screenings Overtail (OT, large pieces of dockage material), hardness, standard 500 ml chondrometer weight (CW) and milling extraction data were compared for 42 wheat samples sourced from Queensland and New South Wales. Similarly barley gradings, roundness and soluble extract data were compared for 41 samples from Victoria, South Australia and Western Australia. Both sample sets were selected to cover an extensive flour yield/extract range. Standard hardness and test milling (Allied Mills, 2003) and malting and mashing (IOB method 2.3, 1999) protocols were followed. A micro SeedCount HW method using a 30.7 ml sample cup was employed and DIA sampling followed the standard SeedCount method (Weiss Enterprises, 2003).

RESULTS AND DISCUSSION

Thickness and Mass

Figure 1 shows that the “flat-edge” indented tray DIA system was able to assess the kernel thickness with reasonable accuracy. The thickness was difficult to estimate due to the relative coarseness of the 300 dpi images (minimum resolution is 0.085 mm) and the tendency of some seeds to be misaligned in the narrow indents. As the width difference of the screening groups is only 0.2 or 0.3 mm, it appears that using higher resolutions and further improvements in the tray design may be beneficial. SeedCount’s success in estimating the kernel mass is shown in Figure 2. The multivariate calculations result in estimates that correlate well (r=0.967) with actual masses. The formula worked similarly with a wide variety of cultivars, suggesting the algorithm is robust. Barley results were similar to those of wheat.



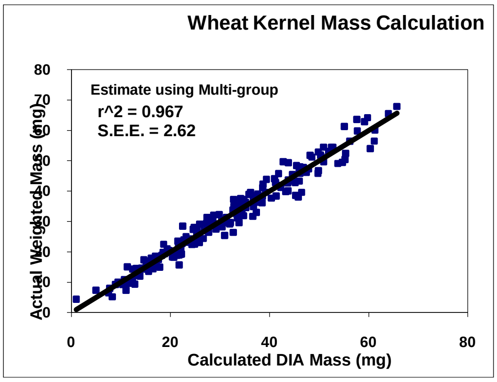


Figure1. Plot of Kernel Thickness vs Calipers

Figure 2. Plot of Kernel Mass vs Actual Mass

Roundness

Individual seed roundness correlations, DIA vs callipers, were acceptable (r = 0.91, std error of 0.02 for barley and r = 0.81, std error of 0.03 for wheat). Full-tray barley cultivars had roundness values ranging from 0.43 to 0.53 with a mean value of 0.49. Wheat cultivars had a mean roundness number of 0.61, ranging from 0.56 to 0.64. Wheat and barley roundness also had a positive correlation (r = 0.77) with screenings greater than 2.8, indicating that the thicker grains also tend to be rounder.

Screenings

The DIA thickness and virtual seed masses were used to generate the screenings groups. Table 1 compares DIA gradings to mechanical screenings for bulk full-tray samples. The largest errors occurred where the median thickness of the sample fell near the breakpoint between two fractions.

Table 1: Screen Grading Accuracy

	> 2.8 Screening	**2.8 - 2.5 Screening**	**2.5 - 2.2 Screening**	**2.2 - 2.0 Screening**	**< 2.0 Screening**	**<2.5 Screening**
Barley Correlation	0.98	0.92	0.86	0.93	0.96	**0.993**
Barley Std Error	6.9	5.2	6.2	4.8	4.6	**4.2**
	> 2.8 Screening	**2.8 - 2.5 Screening**	**2.5 - 2.2 Screening**	**2.2 - 2.0 Screening**	**2.0 to 1.6 Screening**	**<1.6 Screening**
Wheat Correlation	0.89	0.86	0.79	0.97	**0.97**	0.38
Wheat Std Error	12.1	6.8	7.8	1.6	**1.1**	0.4

The most accurate gradings are for the most critical screens (the sum of < 2.5 mm grades for barley and the < 2.0 mm for wheat). The estimates are all highly significant ($p < 0.01$) and will be useful for breeders and others who need a quick estimate of the screen-gradings.

Theoretical Yields

Crewe and Jones (1951) demonstrated that the thickness of cereal bran was stable for a broad range of kernel sizes. This result is applied to barley in Table 2. It is assumed that the husk and bran is uniformly 0.08 mm thick. Table 2 predicts that larger and rounder kernels will contain a higher percentage of endosperm and embryo and thus proportionally more flour/extract should be available. The effect of the embryo on flour yield is ignored:

Table 2: Theoretical Effect of Kernel Volume and Shape on Endosperm

Shape	Length	Width	Thickness	Volume	Percent Endosperm and embryo	Percent Husk and Bran	Roundness Value
Thin Barley	6.8	2.10	1.40	10.47	87.1	12.9	0.394
Average Barley	8.00	3.30	2.40	33.18	91.8	8.2	0.480
Round Barley	9.70	4.10	3.20	66.64	93.5	6.5	0.511
Sphere	4.57	4.57	4.57	49.86	93.6	6.4	1.000

It can be seen that increases in kernel shape and size are linked to increases in the percentage of endosperm. Also of note is that there is only a small gain available in making barley even rounder than our current roundest barley.

Actual Yields

Correlations between the DIA data and other quality data with actual yields were tested. For wheat flour extraction, cultivars with a higher percentage of thick kernels showed a positive correlation with flour yield (eg: $r = 0.54$ for the 2.5 to 2.8 mm fraction, $p < 0.001$). Cultivars with thinner kernels had a negative correlation with yield (eg: $r = -0.59$ for the 2.0 to 2.2 mm fraction). Wheat flour extraction was also positively correlated to roundness ($r = 0.60$, $p < 0.001$, std error 5.7). The correlations are consistent, statistically significant and indicate a general trend towards higher flour yield with increasing kernel thickness and roundness.

Contrary to the usual expectation of higher malt extract yield from larger kernels, Edney, Bassily and Symons (1998) found "consistent and clear trends for smaller kernels to have higher malt extract and better modification (friability)." This study found no significant correlations between extract and screen gradings or roundness in either direction. The poor roundness correlations may be due to variations in the husk on the kernels that make accurate measurements of the kernels, especially the seed length, problematic. Alternatively, the additional endosperm available in the larger kernels may be poorly converted during malting due to their increased distance from the starch degrading enzymes.

Yield Prediction

The DIA wheat yield correlations led to the development of a formula to predict flour yield. Wheat protein levels did not correlate highly with flour yield for this data set. Hardness and CW proved to be strongly positively correlated to higher flour extractions. It appears that the denser, harder kernels allow more complete separation of the bran and better conversion of the endosperm into flour (Dines, 2001). A multivariate approach to the prediction of milling yield resulted in an equation combining the effects of HW, Roundness, 2.0 TO 2.2 mm Screenings, Hardness (in PSI), CW and Screening OT. It has an adjusted R squared correlation of 0.89 and a standard error of 2.9:

Estimated Dirty Wheat flour Extract = -2.819 + 0.2092* HW + 1.793 * Roundness – 0.4009 * Screening + 0.6252 * CW + 0.1044 * Hardness – 0.592 * Screening OT

The wheat samples were cleaned after the Allied Mills tests were run and before the SeedCount testing. This resulted in some differences between the two data sets that would not normally seen, especially in the HW-CW and dockage/screenings OT measurements.

CONCLUSIONS

The "flat-edge" indented tray based DIA system can be used to assess kernel thickness. This, and other DIA data, can estimate the kernel mass and the bulk screening assortment. As well as these values, SeedCount, in less than one minute, can assess the thousand-corn weight, as reported previously, as well as the sample's HW, cross-sectional area and dockage levels (Armstrong *et al*, 2001). Some of these values, coupled with the sample's hardness, can be used to make reasonable predictions of the flour yield of wheat. A more extensive data set would make the equation more robust.

Further software and hardware development allowing the use of higher resolution scans and larger sample sizes will make DIA systems even more accurate.

ACKNOWLEDGEMENTS

The authors wish to thank the Australian Research Council, Wrightson Research, Joe White Maltings and Allied Mills for their generous support.

REFERENCES

Allied Mills; Test Milling Procedures; 2003

Armstrong, B.G., Weiss, M., Greig, R.I. and Aldred, G.P. (2001); Cereals 2001: Proceedings of the 51st Australian Cereal Chemistry Conference; Pg 115-118

Burger, W.C. and LaBerge, D.E.; 1985, Malting and Brewing Quality; in Barley ed Rasmusson, D.C.; Madison, pg 367-401

Crewe, J. and C. R. Jones (1951); Cereal Chem. **28**: 40.

Dines, J. (2001); Cereals 2001: Proceedings of the 51st Australian Cereal Chemistry Conference; Pg 321 -325

Edney, M.J. (1996) Barley, Henry, R.J. and Kettlewell, P.S. (eds), Cereal Grain Quality, London, Pg 113-131

Edney, M. J., Bassily, E. and S. Symons (1998). Proc. Aviemore Conf. Malt. Brew. Distill. **5**: 254-257.

Gebhardt, D. J., Rasmusson, D. C., et al. (1993). J. Am. Soc. Brew. Chem. **51(4)**: 145-148.

Institute of Brewing (1999) Methods of Analysis

Weiss Enterprises (2003) SeedCount Users Manual ver 1.6, Hectoliter Weight