

The Effect of Hammer Mill Screen Size on Processing Parameters and Starch Enrichment in Milled Barley

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ABSTRACT

The influence of two levels of hammer mill screen size on processing parameters and the effect of barley particle size, after segregation by sieving, on starch content and bulk density were examined. Barley grains were hammer-milled through a 2mm and 6mm screens and subsequently fractionated on a set of eight sieves size 0.045, 0.125, 0.250, 0.5, 1.0, 1.7 and 2.8mm. The purposes of this study were to characterize the influence of hammer mill screen size (2 and 6mm) on processing parameters: production output, energy consumption, average particle size (d_{gw}), geometric standard deviation (s_{gw}) and to characterize the influence of particle size, after segregation by sieving, on starch enrichment and bulk density. The results of this study show that increasing the hammer milling screen size has resulted in a significant effect on production output, energy consumption, d_{gw} with no effect on s_{gw} . Different particle sizes, when segregated by sieving, have shown significant effect on starch content and bulk density. Particle size retained by sieve size 1mm had the highest starch content, whereas particles retained by sieve size 0.25mm had the lowest, which suggest potential applications in ruminant and monogastric nutrition. Different measurements of bulk density of segregated particle size suggest the possibility of size fractionation of milled barley particles based on their density differences.

Keywords: Barley; Particle Size Distribution; Hammer Mill, Processing Parameters.

INTRODUCTION

Cereal grains typically are processed before they are mixed into diets for both ruminants and monogastric animals (Svihus *et al.* 2005). This processing very often involves grinding through a hammer mill or roller mill to break the intact kernel and reduce particle size (Amerah *et al.*, 2007). This reduction in size is important to increase the surface area for improving the rate of fermentation and digestion, decrease segregation and mixing problems, and to facilitate further processes such as pelleting (Behnke,

1996; Waldo, 1973). However, from processing perspective, fine grinding may increase the energy required for processing and reducing production capacity of feed mills (Martin, 1984). From nutritional perspective, comparisons of the effects of grain milling on digestibility dose do not take into account the distribution of particle sizes rather limit it to the average as conventional (Al-Rabadi *et al.*, 2009; Wondra *et al.*, 1995c). The objectives of this experiment were to determine the effects of hammer mill screen size on mill production rate and energy requirements for grinding, average particle size, uniformity of ground barley (i.e geometric standard deviation), and starch enrichment of different particle size after segregation by sieving.

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MATERIALS AND METHODS

Barely grinding

Barley (Binalong) was obtained from local market and was milled using a hammer mill (Australian Agriculture Machinery Group, Australia) at 1140 rpm using two screen size (6 and 2 mm). For each hammer mill screen size, grinding was conducted in duplicate. Ground barley was collected at a constant motor load (i.e. constant ammeter reading) during milling. A constant motor load during milling was maintained so that production rates and electrical energy consumption could be measured. Ground barley temperature was measured directly using a thermostat. The ground barley was segregated by size using vertical multiple sieving under gravity with mechanical agitation using a sieve shaker (Endecotts shaker, ExTech Pty. Ltd., Victoria, Australia). Eight screen sieve (Endecotts Ltd, London, England) sizes 2.8, 1.7, 1, 0.5, 0.25, 0.125, and 0.04mm (pan) was selected to give a broad spectrum of particle size.

Sieving analysis

Ground barley was sieved and the geometric mean diameter (d_{gw}) and geometric standard deviation (S_{gw}) was determined with 100 g sample according to (ASAE, 2003) using a sieve shaker for 29 min. In this paper, the term particle size refers to particles that were retained on a particular sieve. Thus, a particle size of 0.50 mm means that the particles in that fraction passed through the 1 mm sieve, and were retained on the 0.50 mm sieve. A particle size of <0.125 mm means the material passed through the 0.125 mm sieve and was collected on the pan. The sieved material obtained, for each sieve fraction size, was kept at 4°C until further use.

Moisture content analysis

Moisture content was determined by drying the ground material in a hot oven at 135 °C for 3 h.

Bulk density

Bulk density was determined by measuring the mass of known volume (50 ml graduated cylinder).

Total starch analysis.

Total starch analysis was performed as previously described by Al-Rabadi *et al.* (2009). Particle sizes above 0.5 mm were ground finely, using mortar and pestle, until the whole sample passed 0.5 mm sieve size. Subsequently, 50 mg of ground samples, controls (5 and 20% (w/w) regular maize starch (Sigma, reference S-5269) mixed with cellulose on a dry matter basis, and reagent blank (empty tubes) were wetted using 0.4 ml of 80% ethanol and then stirred on a vortex mixer. Immediately, 2 ml dimethyl sulfoxide (DMSO) was added, stirred on a vortex mixer and then placed in boiling water for 5 min. Immediately, 0.1 ml of thermostable alpha-amylase (enzyme activity 3000U/ml) from *Bacillus licheniformis* (Megazyme, Ireland, E-BLAAM) in 3 ml MOPS (3-(N-morpholino) propanesulfonic acid) buffer was added. Samples were vigorously stirred on a vortex mixer in a boiling water bath for 12 min (stirring in vortex every 3 min).

The MOPS buffer had been previously prepared by adding 11.55 gm MOPS (Sigma, reference M-9381) to about 900 ml of water and then adjusted to pH 7.0 using 1 M HCl. Calcium chloride dihydrate (0.74 g) and sodium oxide (0.2 g) were added and the final volume was adjusted to 1 liter and stored at room temperature. Samples (5 ml) were then incubated in a 50°C water bath and 4 ml of sodium acetate buffer (200 mM, pH 4.5) was added for each sample and allowed for thermal equilibration for 2min before adding 0.1 ml amyloglucosidase (enzyme activity of 3260 U/ml) (Megazyme E-AMGDP). Samples then were stirred in a vortex and incubated at 50°C for 30 min with gentle mixing at 10 min intervals. After sample centrifugation (for 10 min at 3000 g at 25 °C), the glucose concentration

in the supernatant was determined by using a glucose oxidase colorimetric analysis (Reference TR-1511-200 Thermo Electron Noble Park, Victoria, Australia). Colour absorption was measured at a wavelength of 505 nm (Pharmacia LKB-Ultrospec III, England) and glucose concentration was converted into starch content by applying the factor 162/180 (=0.9) to correct for the loss of one water molecule (molecular weight 18) for every linkage of glucose molecule (molecular weight 180). Starch content for each particle size, controls and reagent blank were analyzed at random and in duplicate.

Experimental design and statistical analysis

A completely randomized design was used in this experiment to evaluate the effect of hammer mill screen size on milling parameters (average particle size, geometric standard deviation, production output, energy consumption). The main factor was the hammer mill screen size (two levels: 6 and 2 mm). The entire design was replicated (two replicas: two batches of barley were obtained, and each batch was milled separately at each mill screen size). This experimental design produced 4 samples. T test was used to examine the differences between the previous parameters. Multiple comparisons of means were performed by using least significant difference (LSD) method, to test the difference between starch content and bulk density for particles retained on different sieve sizes for barley grain milled at 2 mm screen size.

All statistical analysis was performed using SAS software programs (v.9.1, SAS Institute, Cary, NC). For all analysis, the value of α was set to 0.05- the level used for statistical significance.

RESULTS AND DISCUSSION

Effects of hammer mill screen size on processing condition and the fraction yield on each sieve after sieving for ground barley are illustrated in Table 1 and Figure 1, respectively. As shown, reducing hammer

screen size has resulted in a significant reduction in average particle size (d_{gw}). Similar effect of reducing hammer mill screen size on d_{gw} has been reported for different hammer milled grains such as corn (Wondra *et al.*, 1995,a) and in sorghum (Owsley, *et al.*, 1994). In addition, reduction of hammer mill screen size from 9.6 mm to 1.2 mm has resulted in linear reduction in d_{gw} and was associated with reduction in s_{gw} (Wondra *et al.*, 1995a; Wondra *et al.*, 1995b). However, in this study, there was no significant effect of hammer mill screen size on s_{gw} . This may be attributed to that barley grains passed through the 6 mm screen size without any further reduction or breakdown in kernel size as the majority of grains (more than 50% of barley grains) were retained above sieve size 1.7mm as shown in Figure 1.

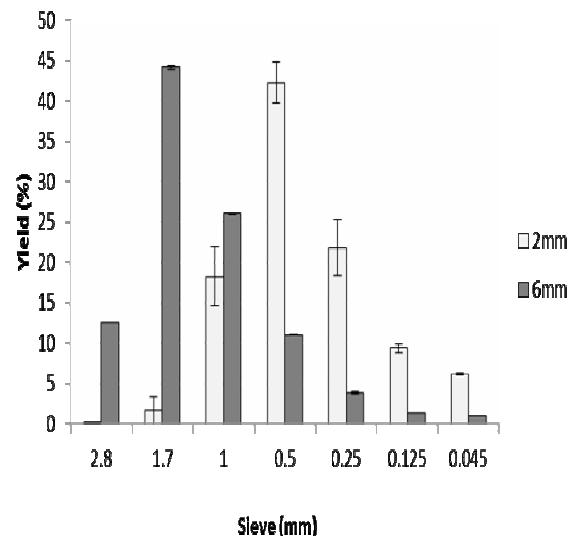


Figure 1. Effect of hammer mill screen size level on particle size distribution of milled barley (Error bar indicates standard deviation).

As d_{gw} was decreased, energy required for grinding increased and production rate declined. The relationship between production rate and energy consumption is illustrated in Table 1. Milling barley using 2 mm screen

size required three times the amount of electrical energy as that by using 6 mm screen size. Fine milling has been previously reported to increase energy consumption (Martin, 1984). The increase in energy consumption and

lower production rate associated with milling barley at 2 mm screen size could be attributed to higher retention time in milling chamber and possibly to higher temperature generated during milling (Table 1).

Table 1. Effect of hammer mill screen size (2 and 6 mm) on processing parameters (average particle size (d_{gw}), geometric standard deviation (s_{gw}), energy consumption, production output and temperature): the overall figures are means \pm standard deviation of duplicate analyses of samples.

Hammer mill screen size	Processing parameters				
	d_{gw}	s_{gw}	Energy (W.h kg^{-1})	Production (kg min^{-1})	Temperature (°C)
2mm	0.56 ^b \pm 0.03	2.09 ^a \pm 0.1	26.81 ^a \pm 3.16	1.33 ^b \pm 0.16	49.25 ^a \pm 0.91
6mm	1.58 ^a \pm 0.01	1.92 ^a \pm 0.01	9.59 ^b \pm 0.74	2.13 ^a \pm 0.21	34.05 ^b \pm 0.35
LSD($P \leq 0.05$)	P=0.005	P=0.14	P=0.017	P=0.05	P=0.008

Differences of mean larger than the least significant difference (LSD), within and across columns, are significantly different ($P \leq 0.05$). Means with the same letter are not significantly different from each other according to LSD different from each other according to LSD comparison.

The effect of sieve fractionation size (1.7, 1.0, 0.5, 0.250, 0.125, 0.045mm) on starch enrichment for different particle sizes are shown in Figure 2. Particles retained by sieve size 1.0 mm had the highest starch content (52.6%) compared to those retained by a sieve size 0.250 mm (39.4%). There was also a trend for gradual decrease in starch enrichment as sieve size decreased (except for particles retained by sieve size 1.7mm). These results show that sieve size can influence starch content of segregated particles and are in agreement with previous studies (Knuckles and Chiu, 1995; Reichert, 1982; Sundberg *et al.*, 1995) which indicates that grain milled and then fractionated (e.g. by sieving or air classification) have different chemical compositions. It would be expected that particles with different chemical composition may have different nutritional and physicochemical properties (Al-Rabadi *et al.*, 2011a; Al-Rabadi *et al.*, 2011b). From a nutritional point of view, grains at same particle size, but different in starch content contribute differently to glucose

absorption flux along animal digestive system (Al-Rabadi *et al.*, 2009; Al-Rabadi *et al.*, 2011a). For example, in broiler, Weurding *et al.* (2003) reported that glucose flux should be available along animal digestive system; diets containing starch that is partially digested in the lower small intestine supply that part with glucose, thereby sparing amino acids from being oxidized. In dairy cattle, Remond *et al.* (2004) reported that starch digestibility decrease with increasing particle size. Large particles have been shown to survive ruminal attack and pass to small intestine for digestion (Galleyan *et al.*, 1981; Owens *et al.*; 1986), thus, particle size of grain can an efficient tool of manipulating rumen degradability of grain starch (Remond *et al.*, 2004). However, it should be noted that the capacity of small intestine to digest starch have been predicated to decrease by half as the amount of starch entering small intestine is increased from 300 to 1500 gram per day in cattle (Huntington *et al.*, 2006).

Differences in particles density are known to cause

segregation and have been anticipated based on potential energy considerations (Hogg, 2009). However, density-difference effects on segregation are still less than those due to size differences (Vallance and Savage, 2000). In this study, different particle sizes, after being segregated by sieving process, have resulted in a significant effect on bulk

density. Bulk density was highest in grain fractions retained by 1.0mm sieve size and was almost double compared with particles passed through 0.250 mm sieve size as shown in Figure 3. These results suggest the possibility of segregating milled barley particle by size based on their density differences.

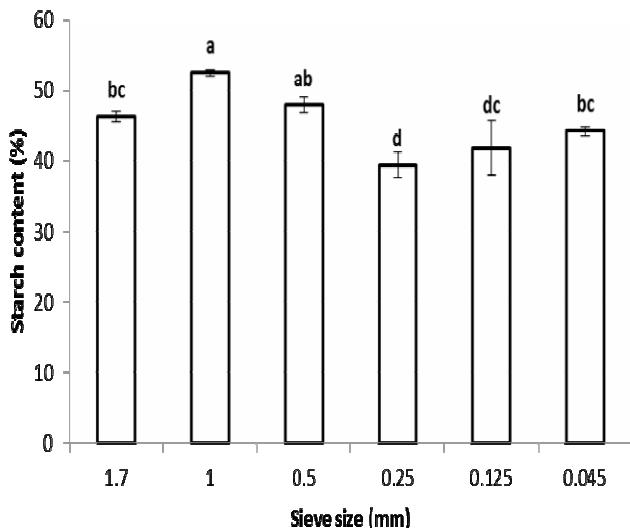
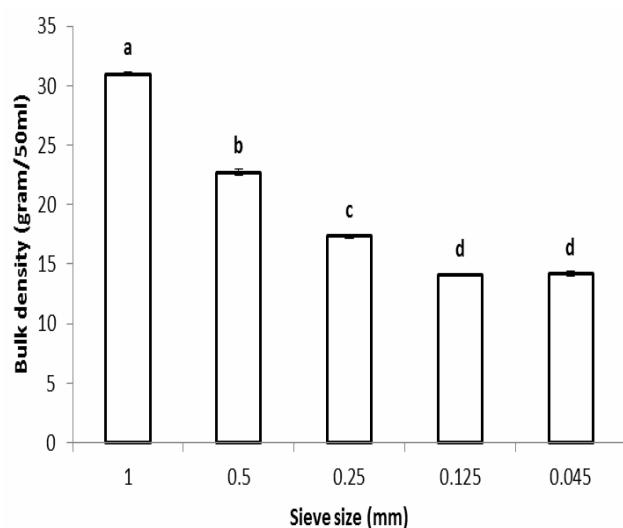


Figure 2. Effect of particle size, after sieve fractionation, on starch content for barley grains milled by using 2mm hammer mill screen size (no grains were retained on sieve size 2.8mm). Column followed by same letters did not differ significantly at $p \leq 0.05$.



Effect of particle size, after sieve fractionation, on bulk density for barley grains milled by using 2mm hammer mill screen size (insufficient material was retained on sieves size 2.8 and 1.7 mm to conduct analysis). Column followed by same letters did not differ significantly at $p \leq 0.05$.

CONCLUSION

It can be concluded from this study that hammer mill screen size have a significant effect on processing parameters such as production output, energy consumption, average particle size (d_{gw}) and ground temperature, while there is no effect on geometric standard deviation (s_{gw}). Different particle size, after segregation by sieving process, had different level of starch content and it would be expected that particles with different chemical composition may have different nutritional and physiochemical properties. Different chemical contents in different size fractions can make diet formulation easier and

economically more profitable if certain fractions are present in sufficient quantities. For example, starch-rich fractions could be used in diets where the energy requirement is relatively high.

RECOMMENDATIONS

Based on the study results, it is recommended to grind barley grains based on weight distribution of particle size, rather than average particle size, by using the proper hammer mill screen size. This approach may provide a better method for specifying processing parameters and nutritive aspects of ruminant and monogastric animal feed.

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$$A = \begin{pmatrix} 2.8 & 1.7 & 1.0 & 0.5 & 0.125 & 0.045 \\ \vdots & (\quad) & & (\quad) & \end{pmatrix} \quad (1)$$

$$B = \begin{pmatrix} 6 & 2 \\ 2 & 1 \end{pmatrix} \quad (2)$$

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