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# Influence of Hammer Mill Screen Size on Processing Parameters and Starch Enrichment in Milled Sorghum

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The effect of hammer mill screen size on processing parameters and particle size of milled sorghum were examined. Sorghum grains were ground through two levels of hammer mill screen size: 2 mm and 6 mm and then subsequently fractionated by size on a set of eight sieves ranging from 0.045 mm to 2.8 mm. The objective of this experiment were: i) to characterize the influence of hammer mill screen size (2 and 6 mm) on processing parameters: production output, energy consumption, average particle size ($d_{gw}$), geometric standard deviation ($s_{gw}$); ii) to characterize the influence of particle size, after segregation by sieving, on starch enrichment. The results of this study showed that using 6 mm 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. Particle size retained by sieve size 1.7 mm had the highest starch content, whereas particles retained by sieve size 0.125 mm had the lowest, which suggest potential applications in ruminant and monogastric nutrition.

**Keywords:** sorghum, particle size, mill, processing parameters

## Introduction

Sorghum is considered as to have a similar chemical composition as corn and thus it can be assumed to have similar nutritive value. However, sorghum has been reported to have lower starch digestibility compared to other grains due to presence of protein matrix that surround starch granules (Al-Rabadi et al. 2009). Therefore, sorghum grains processing before feeding animals are important to enhance overall nutrient digestibility (Amerah et al. 2007). Sorghum grains are usually exposed to grinding process through a hammer mill or roller mill to break the intact kernel and reduce particle size to increase nutrient and energy availability (Wondra et al. 1995a; Svihus et al. 2004). From economical point of view, milling is considered the largest energy cost in layer production when feed is offered mainly in a mash form (Deaton et al. 1989) and the second largest energy cost after pelleting process in broiler production (Reece et al. 1985). The reduction in energy consumption and increasing production output of feed mill can significantly reduce overall

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production cost (Amerah et al. 2007). However, attempts to reduce expenses cost by changing operating variables during milling may have a great influence of final characteristics of milled grains such as grain particle size which is considered the main influential factor in determining nutrient digestibility of sorghum (Al-Rabadi et al. 2009). The objective of this experiment was to evaluate the effect of milling operating condition (screen size) on processing parameters, characteristic of mash sorghum in relation to distribution of particle size and its heterogeneity) and starch enrichment of segregated fraction by sieving process.

## Materials and Methods

*Sorghum grinding*

Sorghum grains were hammer milled by using two levels of screen size: 6 mm and 2 mm. Grinding process was conducted twice for each level of screen size. Ground barley was collected at steady state while milling (constant motor load indicated by constant ammeter reading) so that production rates and electrical energy consumption could be measured. Directly after milling, ground sorghum temperature was measured using a thermostat and stored at 4ºC until further use. The ground sorghum 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 were selected to give a broad spectrum of particle size ranging from 2.8 mm to 0.045 mm (pan) as shown in Figure 1.

*Table 1*. Effect of hammer mill screen size (2 mm and 6 mm) on processing parameters of milled sorghum (data were presented as means ± standard deviation)

| Hammer mill screen size | Processing parameters | | Energy (W.h/kg) | Production (kg/min) | Temperature (ºC) |
|---|---|---|---|---|---|
| | $d_{gw}$ | $S_{gw}$ | | | |
| 2 mm | $0.525^{b}$±0.02 | $1.83^{a}$ ± 0.05 | $14.0^{a}$ ± 1.4 | $1.33^{b}$ ± 0.15 | $42.8^{a}$ ± 1.3 |
| 6 mm | $0.78^{a}$ ± 0.002 | $2.07^{a}$ ± 0.001 | $8.5^{b}$ ± 0.70 | $2.13^{a}$ ± 0.21 | $33.65^{b}$ ± 0.07 |
| P value | 0.002 | 0.07 | 0.04 | 0.05 | 0.009 |

Values within a single column with different superscripts differ significantly ($P < 0.05$).

*Sieving analysis*

Ground sorghum 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 so obtained, for each sieve fraction size, was kept at 4°C until further use. The selected sieves and fraction yield on each sieve after sieving for ground sorghum is shown in Figure 1.

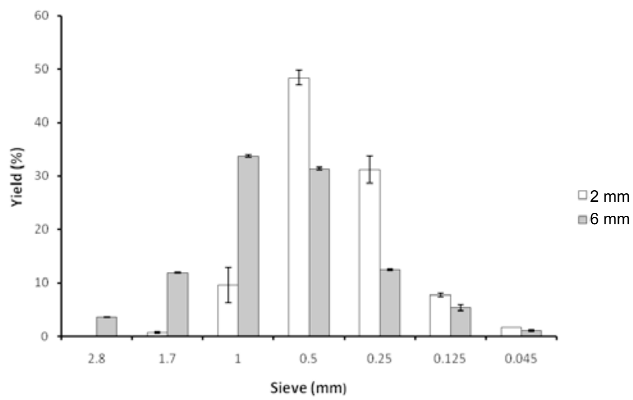


*Figure 1*. Effect of hammer mill screen size level on particle size distribution of milled sorghum (Error bar indicates standard deviation)

*Moisture content analysis*

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

*Total starch analysis*

Starch content was analyzed as previously described by Al-Rabadi et al. (2009).

*Experimental design and statistical analysis*

A completely randomised 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 sorghum 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 for particles retained on different sieve sizes for sorghum 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 $\alpha$ was set to 0.05, the level used for statistical significance.

## Results

The influence of hammer mill screen size on processing parameters is demonstrated in Table 1. As shown and as expected, milling by using 2 mm screen size has resulted in a significant reduction in average particle size ($d_{gw}$ = 0.53 mm) compared to sorghum grains milled by using 6 mm screen size ($d_{gw}$ = 0.78 mm). Although there was significant effect to of hammer mill screen size on average particles size, there was no significant effect of hammer mill screen size on $s_{gw}$. As shown in Figure 1, sorghum grains passed through the 6 mm screen size without any further reduction or breakdown in kernel size as the majority of grains (approximately 50% of sorghum grains) were retained above sieve size 1.0 mm.

As $d_{gw}$ was increased (Table 1), energy required for grinding decreased and production rate increased. The relationship between production rate and energy consumption is illustrated in Table 1. Milling sorghum by using 2 mm screen size required more electrical energy and resulted in a lower production output (14.0 W.h/kg and 1.33 kg/min, respectively) compared to sorghum grains when milled using 6 mm screen size (8.5 W.h/kg and 2.13 kg/min, respectively). The effect of sieve fractionation size (1.7, 1, 0.5, 0.25, 0.125, 0.045 mm) on starch enrichment for different particle sizes are shown in Figure 2. Particles retained by sieve size 1.7 mm had the highest starch content (64.3%) compared to those retained by a sieve size 0.125 mm (55.6%).

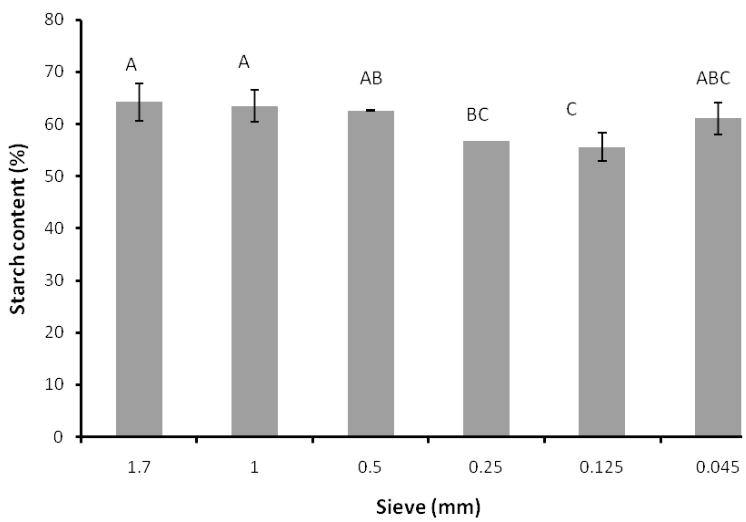


*Figure 2*. Effect of particle size, after sieve fractionation, on starch content for sorghum grains milled by using 2 mm hammer mill screen size (no grains were retained on sieve size 2.8 mm). Column followed by same letters did not differ significantly at $\alpha > 0.05$

## Discussion

Similar effect of reducing hammer mill screen size on $d_{gw}$ has been reported elsewhere for sorghum grains (Owsley et al. 1994). Previous studies have shown that reduction of hammer mill screen over a wide range screen size (from 9.6 mm to 1.2 mm) have resulted in a liner reduction in average particle size of corn grains and was associated with reduction in $s_{gw}$ (Wondra et al. 1995a, 1995b). Particle size have been reported to have a great influence on starch digestibility in raw and in hydrothermal processed grains (Al-Rabadi et al. 2011a). For example, Blasel et al. (2006) reported that for each 0.10 mm increase in particle size in ground maize grain, the degree of starch access by alpha-amylase was found to decrease by 26.8 g/kg starch. Although *in vitro* starch digestibility of milled sorghum grain was not performed in this experiment, it can be safely estimated form knowing the particle size distribution of milled grains (as shown in Figure 1). Recently, Al-Rabadi et al. (2012) showed that *in vitro* starch digestibility can be predicted for non-fractionated milled grains from the weighted distribution of fragments for sorghum and barley grains after digestion at different digestion periods.

Animal feed formulation on the basis of distribution of particle size, may be a better method for specifying feeds for animal growth rather than average particle size as it gives the chance of giving a superior nutrient synchrony between glucose and amino acids through harmonizing digestion kinetics of main nutrients used in animal feed (i.e. starch and protein nutrient sources) (van den Borne et al. 2007). This can be achieved by the inclusion of certain range of particle sizes to provide a wide range of starch fractional digestion rates (Al-Rabadi et al. 2009).

Particle size distribution of milled sorghum can also influence response of milled grains to processing treatments that used to produce animal feed such as extrusion (Al-Rabadi et al. 2011a). Small fraction sizes of sorghum grains (particles smaller than 1 mm sieve size) had shown to have a greater water affinity and responded more to starch swelling and thus gelatinization during hydrothermal treatment (Al-Rabadi et al. 2011b). From animal nutrition prospective, this matter becomes more critical when sorghum milled grains further processed using restricted amount of water such during pelleting process. Svihus et al. (2005) reported that steam conditioning and pelleting resulted in gelatinization of only between 1% and 20% of the starch present. Starch within small particles in sorghum is more rapidly digested (Al-Rabadi et al. 2009) and are the more likely ones to be gelatinized (Onwulata and Konstance 2006). This means that steam pelleting may not induce starch gelatinization of the big particles which are the least digestible and hence most important to gelatinize for enhanced digestibility. In addition, presence of big particles have been reported to produce poor quality of pellets formed due to their low starch gelatinization, compared to pellets made with fine particles (Svihus et al. 2004). The unexpected effect of reducing hammer mill screen size effect on $s_{gw}$ is may be attributed to the size of sorghum grains.

Fine milling has been previously reported to increase energy consumption (Martin 1984) and reduce production capacity of hammer mill (Wondra et al. 1995b). The increase in energy consumption and lower production rate associated with milling sorghum 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).

Few studies reported an economical value of separating milled grain for the production of grain fraction enriched with certain nutrients that have beneficial effects in relation to nutrition and health (Wu and Stringfellow 1992; Srinivasan and Singh 2008; Gunawardena et al. 2010). For example, fractions enriched with high starch can be segregated and included in high caloric diets to maintain energy requirement for high producing animals. However, diet formulation by using starch enriched fraction must be used with care when formulating diets for ruminants. Large particles have been reported to escape bacterial attack inside rumen, due to decrease surface area per unit mass, and pass to small intestine for digestion (Owens et al. 1986). Although enzymatic digestion of starch by animal enzymes is energetically more efficient compared to starch fermentation, the capacity of small intestine to digest starch have been reported to decrease as the amount of starch entering small intestine is increased (Huntington et al. 2006). 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, $d_{gw}$ and ground temperature with no effect on $s_{gw}$ of milled sorghum. 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.

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