Animal Feed Science and Technology 240 (2018) 11–21

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Size distribution analysis of wheat, maize and soybeans and energy efficiency using different methods for coarse grinding

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ARTICLE INFO

Keywords:
Ingredient processing
Hammer mill
Roller mill
Multicracker device
Specific mechanical energy

ABSTRACT

This research investigated three grinding technologies to reduce the size of maize, wheat and full fat soybeans to a course particle. To correct for the different mechanisms of particle size reduction between the different mills, the relationship between specific mechanical energy (SME) and its resulting mean particle size was expressed per ton of ground product. Analysis of covariance was used to estimate differences between the treatment means after correction for energy consumption.

Experimental results, obtained under pilot scale grinding tests, showed that type and conditions used for the three mill types affected size reduction ratios for maize, soybeans and wheat. The RR of particles was smallest for the roller mill and multicracker device and largest for the hammer mill for all feed materials studied and varied between 1.60 (roller mill, wheat) and 5.95 (hammer mill, maize). The mean particle size was smallest when grinding using a hammer mill with a 5 mm screen.

The efficiency of energy use was calculated as effective SME (kJ/kg). Total energy use was shown to be the highest for the hammer mill. Soybeans required the largest amount of energy for grinding, with maize the smallest. The constant for Kick's law (C_k values, kJ/kg) per grinding device was calculated to relate particle sizes and energy demand: both roller mill and multicracker device showed lower C_k values, indicating a better grinding efficiency of these devices.

For coarse grinding, the roller mill was shown to be the most energy efficient device followed by the multicracker device and the hammer mill was the least efficient. For feed manufacturers it is important to use/combine these devices to ensure an efficient milling operation and to match the grinding device with its specific grinding objective (fine, coarse or with a specific particle size distribution). Tasks are different per animal species and were discussed.

1. Introduction

In many cases, diet ingredients are routinely ground prior to their inclusion in animal feeds (Amerah et al., 2007; Thomas et al., 2012). The reduction ratio upon grinding and its resulting particle size distribution are dependent on the type of mill being used and the physical properties of the initial ingredients. In addition, milling variables (e.g. speed, sieve size, roller distance) and the energy used to operate the mill (Fang et al., 1997; Fang et al., 1998) are important. Each mill has a limit to the size of particles it can produce based on principle forces (e.g. impact, compression, attrition) and on attributes (size, hardness, texture) of the feed materials to be

Abbreviations: HM, hammer mill; MC, multicracker; PSD, particle size distribution; RR, reduction ratio; RM, roller mill; SME, specific mechanical energy

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https://doi.org/10.1016/j.anifeedsci.2018.03.010
Received 8 January 2018; Received in revised form 20 March 2018; Accepted 21 March 2018
0377-8401/

ground. The reduction ratio thus may also vary greatly with the feed ingredients being processed.

Particle size is an important characteristic of a feed as it affects voluntary feed intake and the development of the gastro-intestinal tract in avian species (Pérez-Bonilla et al., 2014). The actual particle size differs per feed ingredient when the ingredient is ground using a certain device and, therefore, the device is a causative factor for differences in the coarse structure of laying hen mash diets. The actual particle size consumed by the animal is different in case an agglomeration process (pelleting; extrusion) is applied compared to mash feeding. Normally, a fine mean particle size will be used when agglomerating diets following the grinding process (Hedemann et al., 2005). In pigs for example, coarse grinding does not always permit an optimal nutrient utilization (Svihus, 2011; Laurinen et al., 2000; Potkins et al., 1989). On the other hand, finely ground ingredients may result in dusty products giving rise to respiratory diseases or these may be the cause of gastric lesions in growing pigs (Alaviuhkola et al., 1993).

Hammer mills are used to a large extent for grinding a mixture of feed ingredients for livestock and have achieved merit as these mills are easy to operate and are able to finely grind a variety of diet ingredients compared to other devices (Scholten and McEllhiney, 1985; Islam and Matzen, 1988). Hammer mills produce many small-sized and some coarse-sized particles and are especially used when downstream agglomeration processes are to be used. The energy (kJ/kg of product) required for a hammer mill to grind a particular ingredient varies with the required particle size distribution. It is obvious that a finer grind increases the energy costs and these costs can be dramatically increased when grinding to a mean particle size below 100 µm, for example, for shrimp diets (Obaldo et al., 1999). For feeds with particle sizes more typical of a mash type diet, the roller mill has the advantage of producing more uniform size particles with a lower percentage of fines (Pérez-Bonilla et al., 2014) compared to a hammer mill. However, when this type of mill is used, it is more difficult to grind fibrous materials as is the case for example for barley (Audet, 1995). The roller mill has a better energy efficiency compared to the hammer mill or about equal in the case of flour milling, as discussed by Fang et al. (1997). In addition to the hammer and roller mills employed for the particle size reduction of ingredients in livestock and pet food industries, a further process was developed using converging discs, the multicracker device. In this device, size reduction is established by the cracking action of two rows of discs. The effects of various settings of the multicracker device on the grinding properties of some ingredients was described earlier by Thomas et al. (2012). There is still insufficient data on this latter device in terms of performance relative to hammer and roller milling.

The objective of this study was to compare three feed ingredient size reduction devices (hammer mill, roller mill, multicracker device) by examining the relationship between particle size characteristics and the specific mechanical energy (SME) required during the size reduction of maize, wheat and full fat soybeans to produce ingredients for coarse diets.

2. Materials and methods

2.1. Diet ingredients

Whole seeds of wheat and maize were obtained from Bongers Agro BV (Wilbertoord, The Netherlands) and full fat soybeans were obtained from Schouten Ceralco BV (Rotterdam, The Netherlands). The analysed chemical and physical characteristics of the ingredients are provided by Thomas et al. (2012).

2.2. Specifications of mills

All the equipment used in the current study was properly maintained. The seeds were ground by a hammer mill, roller mill and a multicracker device with each process set at two settings.

The hammer mill (Fransen, Sine loco, The Netherlands) used contained 64 (4 rows of 16) hammers [160 × 50 mm] and was run at a fixed speed of 1475 rpm. The mill engine power was 45 kW and that of the extractor fan 7.5 kW. Sieves of 5 mm (39 holes; 317 rows) or 8 mm (44 holes; 121 rows) were used. The extractor fan was used to ensure the material passed the 5 mm (0.24 m^2 openings, 34% of sieve surface) or 8 mm sieve openings (0.26 m^2 opening, 38% of sieve surface).

The roller mill (Skiold SM4000, Sœby, Denmark) was fitted with one pair of rolls. The roll dimensions were Ø 240 mm by 350 mm. The roll surfaces had a smooth riffle with 4 riffles/cm, riffle height was 1.3 mm. The roller mill engine power was 7.5 kW. The fixed speed of the two rolls was 405 and 505 rpm, respectively with the distance between the roll set at either 0.4 or 1.0 mm.

For the multicracker device (PTW Technologies, Lollar, Germany), two contra-revolving rows of discs were used with the speed of each row of discs being regulated separately. The multicracker engine power was 2 × 18.5 kW. The used discs were either ceramic or steel where the gap between the discs was varied (0.11 or 1.04 mm). The associated capacity at these two gaps was 3.4 and 6.7 ton per hour at discs speed of 2650 or 3800 rpm, respectively. Detailed information pertaining to the multicracker (MC) research has been described previously by Thomas et al. (2012).

2.3. Measurement of process parameters

The ingredient temperature before and after grinding was measured in triplicate by sampling the materials in a Dewar flask and measuring the temperature with a digital thermometer.

Engine power (W) and energy use (Wh) was logged for each individual electric motor using a Janitza (UGM 96S). With the help of its software, energy use per run was calculated. Electricity consumption was measured before and after a run without feed material being ground, the mean of these two runs considered as the idle load of the device. The idle load was subtracted from the total load during grinding for that specific run to calculate an effective energy consumption: the effective SME is the total SME corrected for the