INVESTIGATION OF THE POSSIBILITIES FOR REDUCTION OF THE FINEST PARTICLES DURING THE PRODUCTION OF PELLETED PIG FEED

ABSTRACT

The aim of this experiment was to investigate the possibility to decrease the amount of fine particles in the pellets by coarser grinding of corn before pelleting for the benefit of pigs’ digestive system. Quantity of fine particles after pelleting was more than twenty times higher compared to their quantity before pelleting. Nevertheless, certain combinations of parameters resulted in lower quantity of fine particles and the thickness of the die showed the most significant effect. Coarser grinding of corn before pelleting had some influence on decrease of fine particles in the pellets, but this effect was much weaker than expected. On the other hand, grinding intensity had no significant influence on pellet quality and specific energy consumption of the pellet press, suggesting that coarser grinding of cereals could be applied in the process of pig feed production than it is current practice. This will result in significant energy savings in grinding process.

Key words: corn, grinding, pelleting, pigs, particle size.

INTRODUCTION

Fine grinding of cereals, as main energy source in pig feed, favourably affects digestibility rates in pigs. Consequently, during the last decades there was a trend of higher grinding intensity (GI) of cereals and other components of complete feeds for pigs (Kampeus et al., 2007). On the other hand, experimental investigations suggest that coarse ground diets have favourable effect against Salmonella infections in pigs (Pappenbrock et al., 2005; Kampeus et al., 2005). Also, the development of gastric ulcers and other gastric epithelial alterations that are a worldwide problem in intensive pig husbandry could be reduced by coarser structure of feed. In this respect, it was determined that minimization of fine particles content is the most important, while increasing the proportion of coarse particles in the diet give no ulceroprotection effect (Grosse Liesner et al., 2008). Very often feed for sows, piglets or fattening pigs is not fed as mash but in pelleted form. This is due to numerous advantages of pelleted over mash feed: improved flowability, no segregation of components during transport, minimised feed loses in feeders, positive influence on feed intake and feed conversion (Klausing, 2011) and increase the overall quality of feed ingredients (Kostadinović et al., 2014). During pelleting process, particles of the diet are moulded into cylindrically shaped agglomerates, but this process simultaneously reduces the size of the particles that constitute the pellets (Abdollahi et al., 2013). Grinding of particles during pelleting (secondary grinding) is inevitable and it occurs due to the narrow gap between pellet rollers and the pellet die (Svihus et al., 2004, Vukmirovic et al., 2016) and due to frictional force in the die holes (Abdollahi et al., 2011). The aim of this experiment was to investigate the possibility to decrease the amount of fine particles in the pellets by coarser grinding of corn before pelleting. Concerning that literature data generally suggest that coarse grinding negatively affects pellet quality, thickness of the pellet press die was increased. Increasing the die thickness (DT) should improve pellet quality but it simultaneously increases secondary grinding of particles and specific energy consumption (SEC) of the pellet press. For this reason, moisture content of material was increased. Increased moisture content decreases the pressure in die holes due to lubricative effect of moisture, and thus reduces the extent of secondary grinding and energy consumption of pellet press.


Nomenclature:
DT - die thickness
FP - fine particles
GG - grinding gap
MC - moisture content of ground corn
PDI - pellet durability index
RM - roller mill
SEC - specific energy consumption

MATERIAL AND METHOD

Processing

Grinding and pelleting was performed at pilot-plant facility of the Institute of Food Technology (University of Novi Sad, Serbia). Dent corn (Zea mays indentata) from 2012 harvest was ground using a roller mill (RM) equipped with three pairs of rolls (Model ROSKAMP TP650-9, California pellet mill, USA). The rolls were 165 mm in diameter and 230 mm long and had corrugated surface where number of corrugations per cm was increasing from upper to the lower pairs of rolls and ranged from 1.77 to 5.51 corrugations per cm. Rolls in pairs had different rotational speed and speed ratio of fast-running and slow-running roll was 1.5 : 1. The RM was equipped with dosing system and throughput was set to 870 kg/h. Grinding intensity was set at three levels by adjusting the gap between rolls in pairs (grinding gap, GG) which resulted in three grinding treatments. For each treatment the GG between upper and middle pair of rolls was kept constant at 4.4 and 2.6 mm, respectively, while different granulations were obtained by setting the GG of lower pair of rolls that was set to 1.4, 2.0 and 2.6 mm (treatments RM-1.4, RM-2.0 and RM-2.6 respectively).

Moisture content of ground corn (MC) was set at three levels (14.5, 16.0 and 17.5 %) by the addition of water using double shaft pedal mixer (Model SLHSJ0.2 Muyang, China). Water was added through six nozzles positioned in the upper part of the mixer, above mixing pedals, which ensured uniform distribution. Prepared material was pelleted using flat-die pellet press (Model 14-175, Amandus Kahl, Germany), equipped with two corrugated rollers on vertical shaft driven by 3 kW electric motor, with a rotational speed of 136 rounds per minute. Thickness of the used dies was 24, 30 and 36 mm, while the diameter of die openings was 6 mm. Material throughput was set to 19 kg/h. Specific energy consumption of pellet press was determined by reading out energy consumption value from pellet press display. The pellets were cooled with ambient air for 10 min using fluidized bed cooler/drier (Drier FB 500 x 2000, Amandus Kahl, Germany).

Physical analysis

Particle size distribution of ground corn was determined according to ISO 1591-1 1988 (E) using sieve shaker (Endecotts, UK) with the following size of sieve openings: 7, 5.6, 4, 3.15, 2, 1.6, 1, 0.63, 0.25 and 0.125 mm. Particle size distribution of pelleted material was determined by wet sieving method (Miladinović, 2009), using laboratory sieve shaker (Model AS 200 Control, Retsch, Germany) with following set of sieves: 2.5, 2, 1.6, 1, 0.63, 0.25 and 0.125 mm. Approximately 100 g of pellets was dry sieved using the sieve with 4.8 mm diameter of the openings (0.8 x diameter of sieve openings) in order to separate dust and crumbs (Thomas and van der Poel, 1996). Sample was then soaked in 500 ml of tap water for two hours at room temperature and stirred once after one hour. Soaked pellets were poured onto the top sieve, sieving amplitude was set to 1.2 mm and sample was washed through the set of sieves for 3 x 3 x 3 minutes (for detailed procedure see Miladinović, 2009). Particle size distribution was calculated based on proportion of dry matter left on each sieve after drying overnight at 104°C. Also, dry matter of each sample of pellets was determined using standard procedure (AOAC, 2000) and used for calculation of percent of material left on each sieve, and percent of material that passed the finest sieve (0.125 mm).

Pellet quality was determined as pellet durability index (PDI), which measures the portion of fines generated during standardized mechanical handling. PDI was measured using Holmen Pellet Tester (NHP 100, Norfolk, UK). Duration of treatment was 30 s and fines were removed before and after the treatment using the sieve with 4.8 mm openings diameter. PDI was calculated as the ratio of pellet mass after the test to pellet mass before testing, and expressed as percentage.

Statistical analyses

Box-Behnken experimental design (Montgomery, 2001) was used to evaluate the influence of pelleting variables (3 input factors) and their interactions on the share of the fine particles (FP), i.e. quantity of particles smaller than 0.125 mm after pelleting, SEC of pellet press and PDI. Important characteristic of Box-Behnken experimental design is that it does not contain combinations of parameters in which they are at their lowest or highest levels. In this way experiments with extreme operating conditions were avoided. This was important because under extreme conditions it would not be possible to produce pellets. All variables were arranged at three levels. The maximum and minimum levels of the DT and MC were selected based on previous experiments. It was determined that DT larger than 36 mm and MC lower than 14.5 % and higher than 17.5 % cause blocking of the pellet press. When DT was set to be smaller than 24 mm, it was not possible to produce pellets due to low pressure in the die holes.

Consequently, Box-Behnken design was used for fitting obtained experimental data to second degree polynomial model, this model was applied for description of the responses (R):

$$ R = \sum b_i X_i + \sum b_{ij} X_i^2 + \sum b_{ii} X_i^3 + b_o \quad (1) $$

In equation 1, $X_i$ is independent experimental factor [1 = 1 – 3; 1 – grinding gap of the roller mill (mm); 2 – die thickness of the pellet press (mm); 3 – moisture content of material to be pelleted (%)]; $b_i$ is intercept; $b_i$ is linear effect of the factors, $b_{ii}$ is quadratic effect of the factors and $b_{ij}$ is interaction effect of the factors.

Statistical analysis was carried out using software Statistica 12 and Design-Expert 7 - trial version (Anderson and Whitcomb, 2007). Significance of input factors and interactions in observed model were determined by statistical method of analysis of variance (ANOVA). Sum of squares obtained by ANOVA are used to calculate corresponded contributions. The adequacy of empirical model was determined by coefficient of determination ($r^2$). Also, residual analyses was performed for verification of the obtained models. Directly measured responses, together with data calculated by obtained models, were used in presented figures.

RESULTS AND DISCUSSION

Variables of the pelleting process (GG, DT and MC) were varied according to Box-Behnken experimental design and values of observed responses (FP, SEC and PDI) are presented in Table 1. Regression equation coefficients for simplified models, the level of significance of processing variables, and coefficients of determination of the obtained models are given in Table 2. High values of determination coefficient (higher than 0.8) suggest that obtained models were adequate.
had more than 75% of particles coarser than 2 mm. Energy RM-1.4 treatment). Thus, by applying coarse grinding, high kWh/t for the treatment RM-2.6, compared to 0.39 kWh/t for treatment is compared to the finest grinding treatment (0.19 , but according to our results (Behnke, 2001) pellet quality data generally suggest that coarse grinding compromise the granulation of corn did not have significant influence on PDI numbers before pelleting (3.22, 2.83 and 1.95 for treatments RM-2.6, compared to 0.39 kWh/t for RM-1.4 treatment). Thus, by applying coarser grinding, high energy savings could be achieved in grinding process. Literature data generally suggest that coarse grinding compromise the pellet quality (Behnke, 2001), but according to our results granulation of corn did not have significant influence on PDI (p=0.4209). The most significant influence on PDI had DT (p<0.0001), and pellet quality was strongly increased when thicker die was used (Fig. 2). These results are in accordance with the results of Miladinović and Svihus (2005). Larger DT results in higher pressure in the die holes, better compaction of particles into the pellets, and consequently higher PDI values. But, as it was expected, increasing the DT increased SEC of the pellet press (Fig. 3).

Table 1. The Box-Behnken experimental design and obtained responses

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<thead>
<tr>
<th>Trial number</th>
<th>Input factors</th>
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<tr>
<td>GG (mm)</td>
<td>DT (mm)</td>
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GG – grinding gap of the roller mill; DT – die thickness of the pellet press; MC – moisture content of the material to be pelleted; FP – fine particles (share of particles smaller than 0.125 mm after pelleting); SEC – specific energy consumption of the pellet press; PDI – pellet durability index

Regression parameters: $b_0$ – intercept; $b_1$, $b_2$, $b_3$ – linear effect of the factors; $b_{12}$, $b_{23}$, $b_{13}$ – the quadratic effect of the factors; $b_{12}$, $b_{13}$, $b_{23}$ – the interaction effect of the factors; 1 – grinding gap of the roller mill (mm); 2 – die thickness of the pellet press (mm); 3 – moisture content of material to be pelleted (%); FP – fine particles (share of particles smaller than 0.125 mm after pelleting); SEC (kWh/t) – specific energy consumption of pellet press; PDI (%) – pellet durability index; $r^2$ – coefficient of determination. *Significant at p<0.0001; ** Significant at p<0.05; The level of significance of unmarked values was p>0.05.

Increasing the GG on the roller mill resulted in coarser granulation of the ground material (Fig. 1) with extremely coarse material obtained with GG of 2.6 mm (treatment RM-2.6) that had more than 75% of particles coarser than 2 mm. Energy consumption of the RM was twice lower if the coarsest grinding treatment is compared to the finest grinding treatment (0.19 kWh/t for the treatment RM-2.6, compared to 0.39 kWh/t for RM-1.4 treatment). Thus, by applying coarser grinding, high energy savings could be achieved in grinding process. Literature data generally suggest that coarse grinding compromise the pellet quality (Behnke, 2001), but according to our results granulation of corn did not have significant influence on PDI (p=0.4209). The most significant influence on PDI had DT (p<0.0001), and pellet quality was strongly increased when thicker die was used (Fig. 2). These results are in accordance with the results of Miladinović and Svihus (2005). Larger DT results in higher pressure in the die holes, better compaction of particles into the pellets, and consequently higher PDI values. But, as it was expected, increasing the DT increased SEC of the pellet press (Fig. 3).

Fig. 1. Particle size distributions of corn after grinding. RM – roller mill; 1.4, 2.0 and 2.6 – gap between the lowest pair of rollers of the roller mill (mm)

Due to lubricating effect of moisture, SEC was decreasing with MC increase. Similar results were obtained in the research of Vukmirović et al. (2010). But, beside the decrease of SEC, increasing the MC resulted in slight decrease of the pellet quality (decreased PDI) and higher energy demands for drying/cooling of the pellets with higher MC. Thus, optimal compromise between DT and MC should be determined for each specific case.

Fig. 2. Influence of pelleting variables on pellet durability index

Increased DT enhances physical properties of pellets, but it could be expected that higher pressures in die holes, when thicker die is used, will result in increased secondary grinding. This was confirmed by the obtained results. Quantity of FP after pelleting (particles < 0.125 mm) could be used as an indicator of secondary grinding (Vukmirović et al., 2016). If quantity of FP after pelleting (Fig. 4) is compared with the quantity of this fraction before pelleting (3.22, 2.83 and 1.95 for treatments RM-1.4, RM-2.0 and RM-2.6, respectively) it is obvious that the intensity of secondary grinding was high for all applied pelleting parameters. This was in accordance with the results obtained by Miladinović and Svihus (2005) and Vukmirović et al. (2016). Nevertheless, certain combinations of parameters resulted in lower quantity of FP. As it can be seen from Table 2 and Fig. 4, DT had the most significant effect on the quantity of FP.
grinding of cereals could be applied in the process of pig feed. Significant influence on PDI and SEC, suggesting that coarser achieved. On the other hand, grinding intensity had no differences in particle size distribution after grinding were much weaker than expected concerning that strong distances between particles and resulted in better binding of particles due solid–solid interactions which come into effect when distance between particles is sufficiently small. Higher MC caused better compression characteristics of material and provided more bonds between particles due to capillary sorption (Thomas and van der Poel, 1996; Thomas et al., 1997, 1998).

CONCLUSION

According to presented results, in order to obtain the smallest possible quantity of FP, the smallest possible DT should be used. The limiting fact in this respect is the pellet quality, expressed as PDI, which should not be compromised below the acceptable level by using too thin die. Additional positive effect of using the thinner die is lower specific energy consumption of the pellet press. MC of material did not show significant influence on FP content, and it had a weak influence on PDI. This suggests that the value of this parameter should be adjusted with regard to SEC of pellet press, which was significantly decreased by the increase of MC. Coarser grinding of corn before pelleting had some influence on decrease of FP in the pellets, but this effect was much weaker than expected concerning that strong differences in particle size distribution after grinding were achieved. On the other hand, grinding intensity had no significant influence on PDI and SEC, suggesting that coarser grinding of cereals could be applied in the process of pig feed production than it is current practice. This will result in significant energy savings in grinding process without negative effect on pellet quality and energy consumption of pellet press.

REFERENCES


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