Influence of Various Enzymes and Lignosulphonate on Power Consumption During Pelleting Process and Physical Quality of Pelleted Products

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ABSTRACT

The aim of this study is to evaluate the performance and the effect of various enzymes on power consumption (PC) during ring-die pelleting process and physical quality of the pelleted products. Also, this study evaluates lignosulphonates (LS) as an additive which might aid the enzymes lowering the PC and keeping high physical quality in the pellets. All enzymes reduced PC and the physical quality of pellets. At 2% added water, LS increased the durability of pellets and LS reduced water activity on finely ground barley.

INTRODUCTION

The average cost of electrical power expenditure on feed manufacturing was approximately 85 kWh/tonne in the year 2010 for Western Europe[1]. A typical mill producing annually 250.000 tonnes of feed would be likely to spend € 900.000 on electricity. As a consequence of these costs, the feed industry and the research institutions are trying to increase the power savings for feed production. These savings must be sustainable and without challenging the feed quality or hygiene.

The major PC during pelleting process occurs in the pellet presses by the friction generated by the feed mash located between die and the rollers, nip area[2-4]. The coefficient of friction (μ) is determined by the ratio between the force of friction and the force normal to the die surface. μ depends on the surface of the pelleting die, rollers and the conditioned feed material.

The feed material is initially compacted at the conic die-hole entry, this denser feed-mash produces friction during its pass through the cylindrical die hole which produces even higher densification of the feed mesh. After pellet discharge, the cohesion of the pellet depends on the binding capabilities between particles. Greater binding between particles increases the chance for better physical properties of the feed pellets.

The geometry and surface of the die influences the pellet quality for about 35% [5]. A reduction in friction by the die/roller setting (i.e. at the entry of the die hole) can improve the physical properties of the feed pellets[6]. Enzymes can reduce the viscosity of the cereal grain and hence might reduce friction during pelleting process[7].

Enzymes as the biological catalysts are proven to speed-up reactions during feed conditioning and can also increase the lifetime of the pelleting die due to lower friction and hence slower wear-off. Most commercial enzymes are available in two physical forms, as dry powders and as water soluble liquids. Enzymes are frequently mixed with other feed components before production. Previous evidences shows positive animal growth performance with adding the enzymes at their optimal dosage[7].

However, the literature does not provide information about the influence of various enzymes on PC during pelleting process. Feed pelleting is a thermo-mechanical process and it affects all nutrients in the feed, also enzymes. The relationship between pre-pelleting added enzyme and recovered activity of an enzyme after a thermo-mechanical process, such as pelleting, is of great importance because it can increase the nutritional value of the feed. Therefore, measuring the recovery of enzyme activity (RI) after pelleting is important.

It is known that lignosulphonates (LS) are among the most abundant aromatic polymers. They are highly branched with a wide variety of functional groups. Those groups can provide active centers for chemical and biological interactions. LS are commonly used in the feed pelleting as binders between feed particles which can enhance the strength of the pelleted products. A combination of enzymes and LS might offer an opportunity for the feed industry to decrease PC without challenging the physical quality of feed.

MATERIALS AND METHODS

Experiment 1

In order to understand how a single enzyme or a combination of enzymes might influence PC and the physical properties of a commercial maize based feed, a pilot scale feed production was conducted at the Centre for Feed Technology, FôrTek – Norwegian University of Life Sciences. Grinding the raw materials was done by a hammer mill (Munch, Wuppertal-Germany) fitted with 3 mm screens (HM3). Mixing of the ground ingredients with the vitamine / mineral additives was performed by twin-shaft-paddle mixer (Tatham, 400 liters) during 60 s. The addition of all liquid enzymes into the feed mash was performed by nozzle spraying. Powder enzymes were pre-mixed together with 1 kg of basal diet (BD) before any liquid addition in the mixer. All enzyme products were added during the feed mixing process prior to hydrothermal conditioning and pelleting process. Each type of enzymes were applied at the levels recommended by the manufacturer, AB Vista Feed Ingredients. BD had 8 different treatments with different types of enzyme or combination of different enzymes. Respectfully carried out treatments were:

T1: no addition of water and enzymes.
T2: water addition (WA) 0.2%.
T3: WA 0.2% and 0.01% non-starch polysaccharide (NSP) enzyme Econase™ EXT 25 in liquid form.
T4: WA 0.2% and 0.002% enzyme Econase EXT 5 in powder form.
T5: WA 0.2%, 0.002% enzyme Econase EXT 5 in powder form and 0.0038% enzyme Quantum Blue™ 40 in powder form.
T6: WA 0.2%, 0.002% enzyme Econase EXT 5 in powder form and 0.03% enzyme Quantum Blue 5G in powder from.
T7: WA 0.2%, 0.01% enzyme Econase EXT 25 in liquid form and 0.03% enzyme Quantum Blue 5 in liquid form.
T8: WA 0.2%, 0.01% enzyme Econase EXT 25 in liquid form and 0.03% enzyme Quantum Blue 5 2/2 in liquid form.

A series of pelleting trials, including the same level of steam conditioning, was carried out with a fixed throughput of approximately 1100 kg/h. Each diet was heated prior pelleting at 81°C in a continuous flow conditioner for 30 s. Conditioning temperature was controlled automatically through the Norvidan system. The ring-die pellet press (Munch, Wuppertal - Germany RMP350.100) with two rolls and fixed distance to a die of approximately 1 mm was used. The diameter of the die holes was 3 mm and length 42 mm. PC measurements were performed with a HIOKI™ clamp-on power logger every 60 s during 40 minutes. An average of 10 kg of each sample was collected immediately after pelleting and cooled for 10 min. After

cooling, approximately 2.5 kg of feed sample for each diet was randomly collected for further analyses.

RI was measured by AB Vista Feed Ingredients, Malborough, UK.

Experiment 2

The enzyme with the highest reduction of PC, Econase EXT25™, was chosen based on the results from the first experiment. The focus area of the second experiment was to measure PC when using NSP liquid enzyme during pelleting of ground barley. Also, the focus of experiment 2 was to investigate the influence of LS over the durability and water activity (Aw) of pellets. Grinding for the experiment 2 was done for all 6 mixes by using 3 mm and 5 mm hammer-mill (HM) screens. The mixtures are detailed as follows, fractions are weight basis:

Mix1: 100% barley (ground by HM 3 mm and HM 5 mm).
Mix2: 99.5% barley and 0.5% of LS.
Mix3: 98% barley and 2% of water.
Mix4: 98% barley, 2% water and 0.01% enzyme Econase.
Mix5: 97.35% barley, 2% water, 0.01% Econase XT 25 and 0.65% LS.
Mix6: 97.5% barley, 2% water, 0.01% Econase XT 25 and 0.5% LS.

Mixing and pelleting was performed with the same conditioner and pellet press settings as in the first experiment. The liquid enzyme addition was performed by nozzle spraying. The procedures for LS addition were the same as for powder form enzymes done in experiment 1. The pelleting process was carried out with a steady throughput of approximately 395 kg/h. However, the diameter of the die-holes for the second experiment was 3.5 mm and the length of the pelleting hole 30 mm. Each mix was hydrothermally conditioned prior pelleting at 75 °C in a continuous flow steam conditioner for 30 s. Conditioning temperature was controlled automatically by the PLC controlled system Norvidan. Approximately 5 kg sample for each diet was collected immediately after pelleting and cooled for 15 minutes. After cooling, approximately 1 kg of feed sample for each mixture was randomly collected for further analyses.

PC measurements were performed with HIOKI™ clamp-on power logger every 60 s during 15 minutes.

Moisture analyses were done by standard procedure (EU 71/393) for both experiments. Pellet durability index (PDI %) was measured for each diet for experiment one and for experiment two. PDI was measured by the New-Holmen™ pellet-tester as quadruplicates using approximately 100 grams each. Obtained PDI results were recorded manually. Hardness was estimated through the maximum peak force needed to break a pellet during diametral compression. Hardness analyses were performed only for experiment one by Kahl cylinder tester for each treatment on fifteen pellets of approximately the same length.

A_w measurements were performed for all mixes from the second experiment in order to evaluate the influence of LS on Aw in the diets. HygroLab™ C-1 was used for all Aw measurements.

The software used for descriptive and inferential statistics for experiment 1 and 2 was Minitab v.16. Statistical analyses for experiment 1 included ANOVA analyses and for experiment 2, the experimental data were partially subjected to ANOVA analysis to examine possible effects of the enzyme and LS on the responses: PC, feed moisture and the physical pellet properties. Significant differences between treatments in the experiment 1 were determined by Tukey–Kramer method using 95% confidence interval. To analyse the existence of correlations between variables, a Pearson correlation test with 95% confidence interval was used.

RESULTS AND DISCUSSIONS

Experiment 1

Influence of moisture on power consumption and physical properties of pellets

The results presented in Table 1 are the mean values from experiment 1. The variation in moisture content before pelleting step, within the moisture range from 13.91% to 15.37%, did not influence PC for all treatments according to a Tukey-Kramer test ($p>0.05$) with 0.2% WA (Table 1). This was probably due to the low amount of water added.

After cooling of pellets from T1 to T8, the moisture levels were within commercial values.

Moisture content of pellets had no significant influence on pellet hardness, according to Pearson correlation test (*$p=0.314$)*. However, care should be taken to draw a final conclusion for hardness due to the manual Khal hardness tester, based on a screw and spring system, is not as accurate as most texture analyzers (e.g. Instron, Lloyd, Stable Microsystems, etc.). Further information about Khal tester can be found in literature[8]. However, the moisture content of pellets had a positive influence on pellet durability within the experimental values ($p<0.01$) according to a Pearson test (Fig. 1).

Influence of PC on physical properties of pellets

All different types of enzymes and the combination among them decreased PC when added to BD (Table 1 and Fig. 2). This could be explained by a degradation effect of NSP enzymes. It could be possible that a reduction in viscosity of BD caused by the enzymes lowered the coefficient of friction. The underlying causes for this variability need to be further researched.

The strongest reduction in PC was related to liquid added Econase XT25. Also high durability and hardness were observed. Yet, the highest PDI of the feed pellets was observed in T5 with combined addition of Econase XT5 and Quantum Blue 40 phytase. This combination of polysaccharide-degrading enzymes with phytase exercised a significant effect on PC of T5. This could be explained by the rheological changes occurring in the mash due to a synergistic enzymatic action as found by Caballero et al.[9] High PDI values reported in Table 1 for T5 might be explained by a fact stated by Haros et al.[10], that phytase addition could liberate calcium from the phytate complexes of BD, thus these free calcium ions becomes the binding agents between the feed particles.

Table 1. The experimental production design and the analytical mean results.

Treatment ID	Mash moisture before pelleting (%)	Mash moisture after cooling (%)	PC (kWh/ton)	Durability (PDI%)	Hardness (kg)	Enzyme recovery (%) index VS target
T 1	14,8 b	12.2 c	6,9 d	90,17 d	3,66 a	-
T 2	15,22 a	11.43 b	5,5 c	85,1 c	3,48 a	-
T 3	15,23 a	11.93 c	4,8 a	82.63 b	3,95 a	105
T 4	14,96 ba	11.17 ab	5,1 b	80,5 a	3,65 a	108
T 5	14,36 c	11.3 b	5,2 cb	85,93 c	4,03 a	99
T 6	15,07 a	10.83 a	5 b	80,67 a	3,67 a	114
T 7	14,29 c	11.01 a	5 b	82,2 b	3,63 a	104
T 8	14,25 c	11.15 ab	5 b	82,2 b	3,49 a	106
***p* values**	**0.027**	**>0.001**	**>0.001**	**>0.001**	**0.061**	

Means without common superscripts within a columns are significantly different ($p \leq 0.05$) in one-way ANOVA and Tukey's test

Fig. 3 shows how PC and PDI are linked. This was assessed by a Pearson correlation test ($p<0.05$). This however might not indicate a direct relation between PC and PDI. PC is affected by inter-particle and particle to die friction. Inter-particle friction is known to improve the cohesivity among packed particles[11]. Previously was shown that enzymes affect PC and thus one could infer that enzymes affected inter-particle friction and consequently PC and PDI. This could explain why these two variables linked to particle friction correlate in Fig. 3.

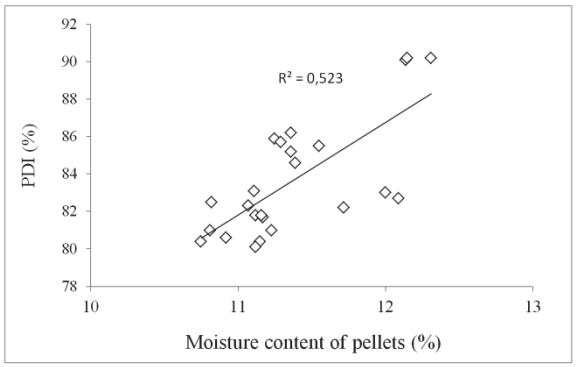

Figure 1. Correlation between final pellet moisture and pellet durability index (PDI %).

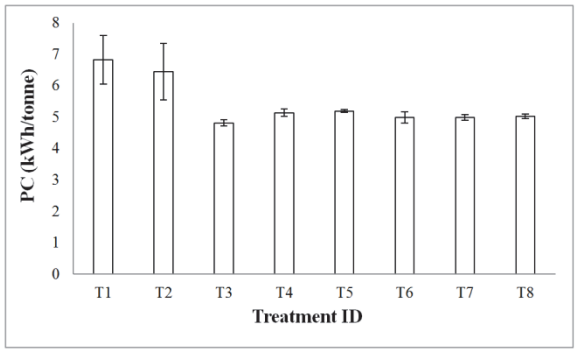

Figure 2. Power consumption (PC - kWh/tonne) with standard errors during pelleting with or without enzymes.

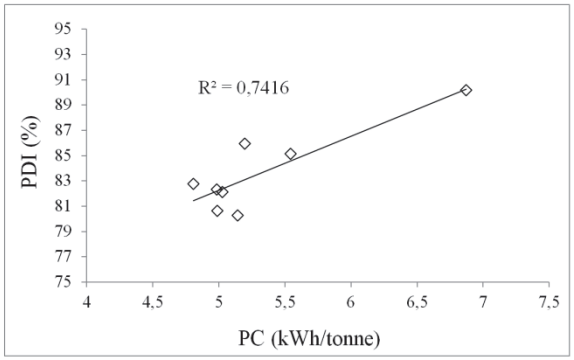

Figure 3. Correlation between power consumption (PC kWh/tonne) and pellet durability index (PDI %).

The assessment of the stability for the enzyme products has required RI measurements of the feed mash prior production and pellets after cooling. Values shown in Table 1 signify that all enzymes or combination of enzymes had the expected or higher RI, according to the producer of the enzymes, at 81 °C conditioning temperatures and pelleted BD when compared to non-conditioned and non-pelleted BD.

Experiment 2

Influence of WA, enzyme and LS on PDI

WA increased PDI for the finest ground barley - HM3-Mix3 ($p<0.05$). However, the opposite was found for the coarser grinding - HM5-Mix3 where WA reduced PDI ($p<0.05$) (Fig. 4). This difference might be explained as water binding capacity is greater with larger contact areas from finely ground barley (HM3) and lower in coarser particles due to limited contact areas. However using a different mixture, Reece et al[12] found the opposite effect, larger particle size lead to a higher PDI.

The addition of enzyme over HM3-Mix3 did not change significantly PDI ($p>0.05$), this can be seen by comparing with HM3-Mix4. Adding enzyme in HM5 Mix4 also had no effect on PDI. No PDI changes could be associated to the low concentrations of enzymes and high amount of fibres.

The addition of LS to ground barley (Mix 2) did not change PDI for both, the finer grinding HM3 and for the coarser grinding HM5. This could be explain by the low amount of added water and because LS requires an optimal amount of water to be an active binder[13]. By adding LS (0.5%) to the mixture with enzyme (0.01%) and water (2%) referred as HM3-Mix4, PDI increased significantly ($p<0.05$) as seen in HM3-Mix6. Similar effect was observed by Ouyang et al.[14] where sufficient water content increased the charge density of LS, possibly indicating a stronger bonding between particles. The same was observed for the coarser grinding (HM5-Mix6). A similar situation was observed by Zulfikar et al.[15] where particle size of the eggshell had no significant effect on LS adsorption.

A further addition of LS (0.65%) did not change PDI for both grinding settings (HM3-Mix5 and HM5-Mix5).

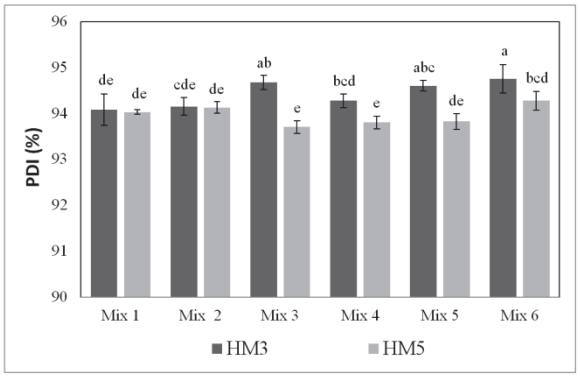

Figure 4. Pellet durability index (PDI) for six different mixtures milled with 3 (HM3) and 5 mm (HM5) screen in a hammer mill. Different letters indicate significant differences ($p<0.05$). Letters are sorted from the highest mean value. Error bars indicate ± standard deviation.

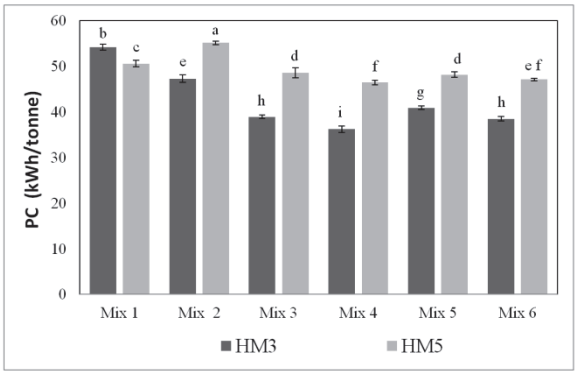

Figure 5. Power consumption (PC) for six different mixtures milled with 3 and 5 mm screen in a hammer mill (HM). Different letters indicate significant differences ($p<0.05$). Letters are sorted from the highest mean value. Error bars indicate ± standard deviation.

Influence of LS, enzyme and WA on PC during pelleting

The influence of LS, enzyme and WA on PC during pelleting is presented in Fig. 5.

Adding LS (0.5 %) into the finely ground barley (HM3-Mix2), significantly decreased PC ($p<0.05$), while the opposite effect was observed for coarse ground barley (HM5-Mix2). More study should be conducted to find the optimum levels of LS addition according to the sizes of the particles.

Adding 0.5% of LS (HM3-Mix6) into ground barley mixed with 0.01% of enzyme and 2% water (HM3-Mix4) significantly increased PC ($p<0.05$). However no change was observed for the coarser mixture (HM5-Mix6). Adding higher amounts of LS (0.65%) significantly increase PC for both grinding settings (HM3-Mix5 and HM5-Mix5). This might be explained by the fact that LS, as strong hydrophilic polymer, have bound water molecules and thus water do not give the same lubrication effect as when unbound.

Addition of 0.01% of enzyme to both HM3-Mix4 and HM5-Mix4 having 2% of added water (HM3-Mix3 and HM5-Mix3) significantly reduced PC ($p<0.05$).

Adding 2% of water to ground barley HM3 and HM5, significantly decreased PC ($p<0.05$). Water addition (2%) to the mixture with LS (0.5%) represented by HM3-Mix6 did not change PC significantly ($p>0.05$).

Influence of LS, enzyme, water content and WA on Aw

The influence of LS, enzyme, water content and WA on Aw is presented in Fig. 6. Fig. 7 shows the relationship between water content of the pellets and Aw as well as minimum Aw values for microbial population growth[16].

According to Fig. 6, adding LS (0.5%) to ground barley (Mix2) significantly ($p<0.05$) reduce Aw for both grinding settings (HM3 and HM5). This can be explained by the strong electrostatic forces between negatively charged sulphonic groups and positively charged hydrogen ions provided by the water[14]. Addition of LS (0.5%) into the mixture having 2% added water and 0.01% enzyme (Mix4), increased Aw for both, HM5 and HM3 in Mix-6. Further addition of LS (0.65%) to Mix4 reduced Aw

($p<0.05$) for the finest ground barley HM3, probably due to the attractiveness between LS and water.

Enzyme addition (0.01%) did not influence ($p>0.05$) Aw for both ground barley HM3 and HM5 and that is not what Maltini et al.[17] found. They stated that enzymes might help hydrating polar or ionic groups in foods. A reason for our findings could be explained by the low amounts of added enzymes (0.01%).

Adding water (2%) increased Aw values for both grinding settings (HM3 and HM5 - Mix3).

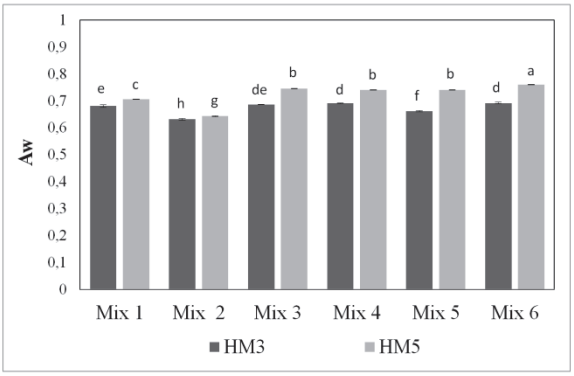

Figure 6. Influence of lignosulphonate, enzyme and water addition on water activity values (Aw) for finer (HM3) and coarser (HM5) ground barley. Different letters indicate significant differences ($p<0.05$). Letters are sorted from the highest mean value. Error bars indicate ± standard deviation.

The moisture content of pellets for all grinding settings, HM3 and HM5, influenced Aw values. An increase in Aw can be seen from Fig. 7. The moisture content of pellets for both, finer (HM3) and coarser (HM5) ground barley correlated to the Aw values, $p=0.005$ for HM3 and $p=0.003$ for HM5, according to a Pearson correlation test with 95% confidence interval.

It also can be observed from Fig. 7 that the coarser mixtures (HM5) presented higher Aw values compared to the finer mixtures (HM3).

The pellets for the HM5 presented a larger range of moisture values compared to HM3. HM5 pellets presented the "driest" and "wettest" pellets.

Understanding better how the effect of varying doses of phytase and NSP enzymes in addition to different LS levels interact with different feed ingredients in regards to PC and on PDI of pellets should be further researched.

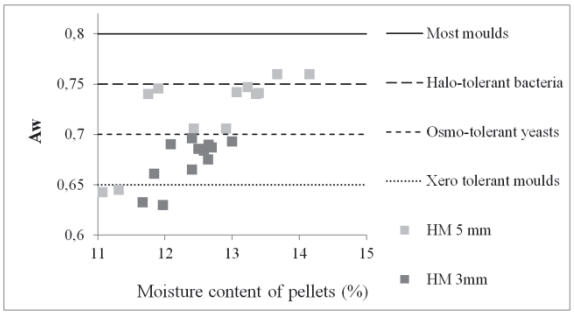

Figure 7. Moisture content of pellets (%) and water activity values (Aw) for all mixtures. The plot also shows the minimum water activity for microbial population growth[16].

CONCLUSIONS

The enzymes tested, regardless of its form, powder or liquid, have lowered power consumption during pelleting. The largest reduction in power consumption, ~30%, was observed when using liquid Econase XT 25 on a basal diet with maize as the mayor component. A reduction of ~26% in power consumption was found when using NSP enzyme in powder form.

The study also found that lignosulphonate decrease water activity and increase power consumption at low water contents on ground barley. At higher water contents, lignosulphonate did not increase power consumption.

ACKNOWLEDGMENTS

Thanks to Paul Steen (AB Vista Feed Ingredients, Marlborough, UK) for generous contribution by providing the enzymes for this research and RI analysis.

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