PELLETING MODERN BROILER FEEDS: WHY, WHAT AND HOW

M. Reza Abdollahi, V. Ravindran
Monogastric Research Centre, School of Agriculture and Environment
Massey University, Palmerston North 4442, New Zealand

1.- INTRODUCTION

To achieve the genetic potential of modern meat-type birds, feed intake (FI) must be tightly monitored and maximised. Any strategy, including feed processing, capable of increasing feed consumption and alleviating the FI stressors will improve broiler production. Currently, majority of the feed used in the production of broilers is fed in pelleted or crumbled form. There are several mechanisms that underpin the advantages of pellet feeding over mash diets, but the foremost factor is simply the increased FI through facilitation of easy ingestion. Though the nature of digestibility response is dependent on the ingredient and the specific nutrient, recent evidence suggests that pelleting has no positive impact on the digestibility of major nutrients in cereal-based poultry diets. However, the efficiency of feeding pelleted feed to broilers in determining the actual performance responses depends on the dietary nutrient density, and nutrient availability which, in turn, is influenced by grain type, and processing variables such as particle size reduction and conditioning temperature. To maximise pelleting benefits, it is critical to decide which level of nutrient density should be used and to identify manufacturing techniques to create high quality pellets that are highly digestible.
2. WHY TO PELLET: MOTIVATIONS BEHIND THE PELLETING OF MODERN BROILER FEEDS

It is nearly a century since the pelleting process was introduced to the United States feed industry by Purina in the mid-1920's (Coffey et al., 2016). Since its introduction, pelleting has become the most common hydrothermal process in the preparation of broiler diets on a global basis. Feeding pelleted diets, regardless of cereal type and bird age, has long been shown to improve growth rate and feed efficiency in poultry (Abdollahi et al., 2018b). These improvements have been attributed to a number of factors. Pelleting reduces feed wastage, which may be attributed to less particles falling from the beak onto the floor or into the water. Pelleting also prevents birds from selecting larger particles from mash feed and the messy sorting which may cause feed to be pushed out of feeders and increase feed wastage. Even a homogenised and balanced mash diets may fail to meet the nutritional requirements, if the birds pick out only the large particles. By preventing sorting, pelleting ensures that birds receive the complete diet and thus a balanced concentration of nutrients. Pellet-fed birds spend less time and energy in the ingestion of feed and obtain more nutrients per every unit of expended energy than those fed mash diets (Jones et al., 1995). In a study by Jensen et al. (1962), mash-fed chickens (21-28 d) spent 14.3% of a 12-hour period eating versus only 4.7% with pellet-fed chickens. These researchers observed a similar trend with greater difference for poults (38-45 d), with those fed mash using 18.8% of the 12-hour day eating while poults fed pellets used only 2.2%. Pelleting increases the bulk density of mash feed allowing more efficient transportation and enhances flow properties of feed. Decreased feed dustiness, both in feed mills and poultry houses, is another important positive aspect of pelleting.

Modern meat-type birds have a voracious appetite and, therefore, their FI must be tightly monitored in order to achieve their high genetic potential. It has been well documented that feeding pelleted diets results in marked performance improvements in fast growing birds mainly through increased feed consumption. Feed intake is the major factor driving body weight gain and the fact that the beneficial effects of pelleting on broiler growth always parallel the effect on feed consumption, the improved performance could be, to a major extent, attributed to the stimulatory effect of pellet feeding on FI (Engberg et al., 2002; Svihus et al., 2004; Abdollahi et al., 2013a, 2014). The increase in bulk density of pelleted diets, which facilitates easy prehension, may largely account for the higher feed consumption in pellet-fed birds. Increased FI due to pelleting broiler diets has been reported to vary from 2.8% (Serrano et al., 2012) to 64% (Amerah et al., 2007). Abdollahi et al. (2011) reported a 14% increase in the FI of broilers due to pelleting during the starter phase (1-21 d of age). Increased feed intake resulted in higher intakes of digestible protein (250 vs. 226 g/bird) and AME (15.90 vs. 14.26 MJ/bird) in pellet-fed birds compared to mash-fed birds. Lilly et al. (2011) showed that increasing percentage of intact pellets from 30 to 60 and 90% in a broiler diet, primarily increased FI and consequent body weight.

Svihus et al. (2004) suggested that higher FI increases weight gain and reduces the proportion of energy used for maintenance in relation to gain. Therefore, improved productive energy may be observed with pelleting. Productive energy is an estimation of the MJ per unit of feed actually used for lipid and protein accretion (Reddy et al., 1962).
Reddy et al. (1961) observed that chickens fed pellets spent approximately 4% of their time in the ingestion of feed compared with 15% for mash-fed birds. By determining the productive energy content, it was also noted that the pelleted diet contained more productive energy than the mash diet. According to McKinney and Teeter (2004), energy content of a diet with good pellet quality could be reduced without compromising the growth response. It was reported that pelleting contributed 0.78 MJ MEn/kg of diet at 100% pellets (no fines), with this value decreasing with increasing proportions of fines to pellets, but still contributing 0.32 MJ MEn/kg for 20% pellets. Skinner-Noble et al. (2005) reported a contribution of 0.63 MJ MEn/kg of diet from pellets compared to mash diet. A recent study by Latshaw and Moritz (2009) showed that the energy from each unit of feed that was utilised for production and heat increment was affected by feed form. Broilers fed pellets had lower heat increment and utilised more of the feed energy for productive purposes than those fed mash. The positive effect of pelleting on feed efficiency is partly due to the reduction in feed energy used for maintenance resulting from the increased FI and thus weight gain.

The fact that feeding pelleted diets, in contrast to general belief, does not enhance nutrient digestibility further emphasises the importance of FI in achieving the considerable advantages of pellet feeding over mash diets in broilers. Feeding pelleted diets, in general, either adversely influenced energy utilisation and nutrient digestibility in wheat- and sorghum-based diets, or had no effect on the digestibility of major nutrients (nitrogen and starch) in maize-based diets (Hetland and Svihus, 2001; Abdollahi et al., 2011, 2013a, 2014; Selle et al., 2012, 2013). Therefore, it seems that improvement in growth rate and feed efficiency of pellet-fed birds to be essentially a result of reduced feed wastage, more feed and nutrient intakes and not efficient nutrient utilisation.

3.- WHAT TO PELLET: TOWARDS A PELLET-APPROPRIATE APPROACH

3.1.- Dietary nutrient density influences effectiveness of pellet-feeding

The fundamental objective of pelleting at the time of introduction to the feed industry was to convert fibrous, bulky, finely-ground and unpalatable blends of feed ingredients into a compact, free-flowing pellets that facilitate easy prehension (Brickett et al., 2007; Coffey et al., 2016). A perusal of the intervening period shows that the genetics, management, nutrition, feeding practices and, most importantly, diet composition that are used in contemporary chicken-meat production have changed substantially and that the majority of current diets are steam-pelleted. The most momentous change in broiler diets over these years has been the shift from fibrous, textured and poorly digestible feedstuffs, to low fibre, texture-less and nutrient-enriched diets. This transition not only hinders the development, functionality and health of the gastrointestinal tract (GIT), affecting nutrient digestibility (Svihus, 2011; Mateos et al., 2012), but is a limitation to some of the advantages generated by steam-pelleting.

Despite the potential for interactive effects between nutrient density and feed form in poultry, few studies (Lemme et al., 2006; Brickett et al., 2007; Saldana et al., 2015) have
investigated this possible interaction. In a recent study (Abdollahi et al., 2018a), we investigated the interaction between five dietary nutrient densities (differing in 100 kcal AME/kg and 0.48 g lysine/kg) and two feed forms (mash vs pellet). Predictably, birds fed pelleted diets outperformed those fed mash diets at each density, however, the pellet-associated benefits were more pronounced at the lower nutrient density, confirming an interaction between nutrient density and feed form. Pelleted diets supported a better weight gain by 17.1% (977 versus 834 g/bird) but this advantage was progressively diminished from 33.9% in very low density diets (983 versus 734 g/bird) to 6.0% in very high density diets (953 versus 899 g/bird). Similarly, pelleted diets supported higher FI by 16.3% (1248 versus 1073 g/bird) but this advantage was eroded from 23.3% in very low density diets (1322 versus 1072 g/bird) to 9.8% in very high density diets (1149 versus 1046 g/bird).

These outcomes are not without precedents. In a comparison of mash versus crumbled diets, Shen et al. (1985) found that crumble-fed birds outperformed mash-fed birds on low energy diets but this was not the case with high energy diets. Leeson et al. (1999) reported that pelleting a low nutrient density diet enhanced weight gain by 15% (540 g) but this advantage was eroded to 8% (317 g) with a highly nutrient dense diet. Brickett et al. (2007) increased the dietary nutrient density from low (11.7 MJ AME/kg, 11.6 g lys/kg) to medium (12.3 MJ AME/kg, 12.3 g lys/kg) and high (13.0 MJ AME/kg, 12.9 g lys/kg) levels. These researchers reported that the advantages of pelleting for FI were diminished from 462 to 366 and 345 g/bird and, similarly, body weight advantages declined from 289 to 223 and 188 g/bird.

Pelleting is a costly process but it is usually more than justified by the enhanced growth performance. However, that pelleting diets attenuates the negative effects of feeding bulky, fibrous and less nutrient dense diets on broiler growth performance as in the above-mentioned studies indicates that pelleting can facilitate the incorporation of more inexpensive and less palatable feedstuffs into practical broiler diets. Looking more closely at the diets used in our recent study (Abdollahi et al., 2018a), the changes in the composition of the diets from very low to very high diets do resemble the changes made to the composition of broiler diets over time since the introduction of the steam-pelleting process. Despite the remarkable progress in poultry nutrition achieved over recent decades, it appears that the chicken-meat industry has, by increasing dietary nutrient densities, in order to minimise the feed conversion ratio, progressively disregarded the initial and core objectives of pelleting, and in so doing, the cost-effectiveness of the steam-pelleting process is being harnessed to a lesser extent.

One implication of the previous studies (Leeson et al., 1999; Brickett et al., 2007; Abdollahi et al., 2018a) is that if diets for modern broilers are to be pelleted they do not need to be formulated to high levels of nutrient density. While a nutritionally dense diet is required when fed as mash because lower nutrient densities could not be compensated for by higher FI in mash-fed birds (Lemme et al., 2006), the pellet-appropriate approach could involve the use of more fibrous, bulky, less palatable ingredients to formulate lesser density diets. There are several avenues by which the chicken-meat industry could benefit by adopting steam-pelleted diets with lower nutrient density levels. However, identifying
the optimum nutrient density to be used in pelleted diets will require further applied research that considers issues of economics.

3.2.- Pellet-appropriate assays for nutrient requirements and feed ingredient evaluation

Amino acid (AA) requirements of broilers have been shown to vary depending on feed form (Jensen, 2000; Greenwood et al., 2004; Lemme et al., 2006). This calls into question the application of AA recommendations determined in assays based on purified, semi-purified and dose-response diets fed, in most cases, in mash form. This scenario might also apply to other nutrients and highlights the need to re-evaluate nutrient and energy requirements of modern pellet-fed birds using entirely appropriate assays. Besides nutrient requirements, feed texture and modifications associated with the pelleting process also play a defining role on nutrient digestion and energy utilisation, with the nature of digestibility and utilisation responses to pelleting is both ingredient- and nutrient-dependent (Abdollahi et al., 2013a, 2014; Naderinejad et al., 2016; Roza et al., 2017). Collectively, these studies provide a compelling rationale for the appropriate re-evaluation of digestible AA content, and even digestible Ca and P content in the current era when there is a move towards the adoption of the digestible Ca and P concept, and metabolisable energy content of individual feed ingredients using pelleted diets.

4.- HOW TO PELLET: DILEMMA OF PROCESSING EXTENT

4.1.- Feed particle size

The gastrointestinal tract (GIT) plays an important role either directly or indirectly on birds’ health through various physiological functions. A well-developed gizzard enhances the grinding action, generates stronger reverse peristalsis contractions within the GIT, increases proteolysis by pepsin and stimulates secretion of hydrochloric acid which reduces the pH. Harmful bacteria entering the intestinal tract via the feed have a greater chance of being suppressed in a highly acidic environment. It is being increasingly recognised that the broilers may have a requirement for a certain level of structural components such as coarse particles, insoluble fibre sources and whole grains in their feed to meet their innate feeding behavior development (Ferket and Gernat, 2006). The major motivation for inclusion of structural components in poultry diets is to stimulate gizzard development and functionality which will favourably influence gut health and the bird’s ability to better utilise nutrients. The beneficial effects of such practices may also extend to their favourable influence on intestinal morphology and functionality (Amerah et al., 2007) and microbiota profile (Engberg et al., 2002).

Due to possible impairment of pellet physical quality associated with large particles, fine grinding is generally favoured to obtain a high pellet quality. However, coarse grinding of maize has been reported to have no negative effect on pellet quality, determined as PDI, hardness and percentage of intact pellets, compared with medium or fine grindings (Reece at al., 1986; Amerah et al., 2007; Naderinejad et al., 2016).
Meanwhile, because it is not possible to avoid further particle size reduction during the pelleting process, fine particles are almost inevitable during pelleting and this results in a suboptimal gizzard development with potential negative influence on nutrient digestibility. An elevated gizzard pH and a short digesta retention time, due to an under-developed gizzard, are physiological limits to optimal digestion in poultry. This complex matrix of conditions (pH and retention time) becomes even more limiting when birds are fed pelleted diets (Abdollahi et al., 2013a). According to Liu et al. (2015), a negative correlation (r = -0.451) exists between relative gizzard weight and gizzard pH. There is evidence of relatively higher gizzard pH in birds fed pelleted diets compared to those fed mash diets (Huang et al., 2006; Frikha et al., 2009; Saldana et al., 2015), attributed mainly to the pH of feed (5.5 to 6.5), higher FI and possibly lower hydrochloric acid secretion (Svihus, 2011). Under the current system of continuous feeding, the function of the crop as a storage organ appears to be lost. Gizzard is not fully developed when feeding pelleted diets and a less developed gizzard serves as a transit organ rather than a grinding organ, with the implication of reduced retention time. The average retention time in the digestive tract, excluding the caeca, is probably around 3 to 4 h (Svihus, 2011). Of this, digesta possibly spends only 60 to 90 min in the anterior digestive tract, which gives only limited opportunity for enzyme action. Naderinejad et al. (2016) reported that the gizzard pH was responsive to particle size only in pelleted diets. Although pelleting reduced the proportion of coarse particles, it seems that a minimum of 4 to 6% coarse particles of > 2000 µm was sufficient to stimulate hydrochloric acid secretion and reduce the gizzard pH to the same level as mash-fed birds. When pelleted diets are fed to broilers, the use of coarse particles does not seem to depress the growth performance and could possibly optimise intestinal development and function. Increased gizzard weight with coarse particles in pelleted diets seems to have a positive effect on the gizzard pH and increased nutrient digestibility and energy utilisation. As broiler diets are usually pelleted, it would appear that coarse grinding could be beneficial for nutrient and energy utilisation in broiler chickens while maintaining physical pellet quality. Moreover, coarse grinding in pelleted diets would also be preferable because of considerable energy saving may be achieved by increasing the sieve openings.

4.2.- Conditioning temperature

Currently, majority of the feed used in the production of broilers is fed in pelleted or crumbled form. One of the major issues in the manufacture of pellets is the application of high conditioning temperatures. The need to reduce potential levels of feed-borne pathogens such as salmonella and campylobacter for feed safety and to achieve high pellet quality has led to the application of relatively high (between 80 and 90 ºC) conditioning temperatures during conventional pelleting processes, a practice which may not favour high nutrient availability. However, the true impact of conditioning temperature on the nutrient availability of pelleted diets has not been clearly delineated due to the confounding effects of conditioning temperature and feed form or has been ignored due to the focus on physical pellet quality and feed safety.

By differentiating the effects of conditioning temperature from feed form, Abdollahi et al. (2011) showed that application of high conditioning temperatures per se
adversely influenced starch digestibility and energy utilisation in wheat-based diets. These researchers reported decreases in starch digestibility from 0.98 in diets conditioned at 60 ºC to 0.94 and 0.91 in diets conditioned at 75 and 90 ºC, respectively. Increasing conditioning temperatures above 60 ºC also reduced the AME of diets from 14.2 MJ/kg in diets conditioned at 60 ºC to 13.9 MJ/kg in those conditioned at 75 and 90 ºC. In a recent study with maize-soybean meal diet, Loar II et al. (2014) found that as conditioning temperature increased from 74 to 85 and 96 ºC, digestibility of some AA decreased by 3 to 5%, and feed per gain was impaired by 3 points (1.96 vs 1.99) and 8 points (1.96 vs 2.04), respectively.

Cowieson et al. (2005) reported a significantly higher dietary viscosity for pelleted wheat-based diet than that of the mash diet when no xylanase was added, whereas the addition of xylanase reduced the viscosity to that of the mash diet. The increases in viscosity from mash to pellet diets conditioned at 80, 85 and 90 ºC were 53, 116 and 121%, respectively, for the starter diet and 57, 83 and 76%, respectively, for the finisher diet. Increased diet viscosity was attributed to an increased solubility of NSP. It was also suggested that the negative effect of conditioning temperature on viscosity is primarily responsible for the poorer performance of birds fed high-temperature conditioned diets. Their conclusion was supported by the fact that the addition of exogenous xylanase markedly improved the performance of birds fed diets with higher viscosity, but failed to improve the performance of those fed the diet that was pelleted at the lowest temperature and had the lowest viscosity. These results are in agreement with those of Samarasinghe et al. (2000) who reported higher dietary viscosity due to high conditioning temperatures (75 and 90 ºC) during pelleting a barley-maize-soy diet compared to 60 ºC. Although supplemental enzyme reduced the dietary viscosity at all three temperatures, its effect was greater at higher temperatures (11, 14 and 17% reduction in viscosity of the diets conditioned at 60, 75 and 90 ºC, respectively). Enzyme addition increased the weight gain of broilers by 11.1% at 90 ºC, but had no effect at low temperatures. Viscosity is a composite of soluble carbohydrate concentration and more importantly the degree of polymerisation or the molecular weight of carbohydrate (Izydorczyk and Biliaderis, 1992; Cowieson et al., 2005). The viscosity of a solution can be extremely high, even if the solution contains a low concentration of soluble polysaccharides, if the soluble polysaccharides are of a sufficiently high molecular weight (Cowieson et al., 2005). As increasing conditioning temperature can destroy the activity of diet endogenous (Silversides and Bedford, 1999) and microbial (Cowieson et al., 2005) enzymes which degrade xylans, this contributes to an increase in molecular weight (i.e. less depolymerisation of carbohydrates). Therefore, it is possible to have increased viscosity in diets conditioned at higher temperatures regardless of soluble carbohydrate concentration. Heat treatment of diets containing specific types of fibre may affect nutrient availability negatively both through increased viscosity and reduced activity of the enzymes added to alleviate this problem.

It seems that under the conventional pelleting process, which uses high conditioning temperatures, good pellet quality is obtained at the expense of nutritional quality. There are several strategies that can be employed to improve the physical quality of the pellets, instead of applying high conditioning temperatures. Pre-conditioning
moisture addition in the form of water, and to lesser extent pellet binder addition, and using small diameter die holes and longer pellet lengths can create high quality pellets under low conditioning temperature (Abdollahi et al., 2013b). More research, however, is still required to identify and evaluate other possible approaches to manufacture high quality pellets at low conditioning temperatures.

The only remaining concern is the need to eliminate salmonella in feed, which is thought to require high-temperature heat treatment. However, it should be noted that the temperature is not the only factor required for eliminating salmonella and that heating time and moisture content are also important. McCapes et al. (1989) suggested that a combination of 85.7 ºC conditioning temperature, 4.1 min heating time and 145 g/kg moisture was required in pelleting process to be 100% effective against salmonella and E. coli. In conventional pelleting operations, these temperature and moisture conditions are achievable, but the retention time of the mash inside the conditioner is usually far less than the time suggested. By comparing pelleting temperatures with salmonella contamination rates at the exit of three different pellet mills, Jones and Richardson (2004) suggested that applying high temperatures during pelleting does not guarantee salmonella elimination and that the sanitising effects of pelleting may be lost by dust contamination around the pellet mill. Heat-treated feed may also be re-contaminated during transport and delivery. According to Creswell and Bedford (2006), the move towards higher temperatures to sterilise feed can increase intestinal viscosity in birds fed diets based on viscous grains and lead to excessive growth of gut microflora. These effects can unwittingly make the bird more susceptible to other infections such as necrotic enteritis. Although heat treatment is currently thought to be the most practical method to achieve satisfactory feed safety, but, considering the rising cost of feed ingredients and the negative impact of high conditioning temperature on nutrient availability and feed efficiency, there is a need to find new approaches of improving feed hygiene which are not detrimental to feed nutrients.

5.- CONCLUSIONS

Whilst the importance of feeding pelleted feed to broilers is no longer questionable, its efficiency in determining the actual performance responses depends on nutrient availability which, in turn, is influenced by grain type, processing variables such as conditioning temperature, feed texture and birds’ digestive tract development. The current practice of high degree of processing of feed, which induces particle size reduction and increased FI, and ad libitum feeding does not support the normal development and functionality of the foregut. Incorporation of structural components to poultry diets can impart some benefits to the birds’ digestive system, especially in contemporary diets which lack feed structure. It is tempting to suggest that more benefits from steam-pelleting could be realised with diets of lesser nutrient densities, therefore a pellet-appropriate approach should be adopted for formulating broiler diets. In this approach, dietary nutrient density should be taken into account to maximise the benefits generated by the steam-pelleting process. However, identifying the optimum nutrient density to be used in pelleted diets will require further applied research that considers issues of economic. Based on available data, it is also reasonable to assume that nutrient requirements of modern broilers may depend
on feed form and there is a need to determine nutrient requirements of broilers using pelleted diets.

6.- REFERENCES