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The impact of feed treatment on the performance of broilers: A review

Abstract

Commonly used treatments of poultry feed, such as pelleting, expanding or extrusion increase the physical density of the feed and lead to increased feed intake, reduced time spent feeding, improved growth rate and improved feed to gain ratio. Subsequently, improved feed conversion and better performance can often be observed when feeding processed diets compared to mash. Other benefits of thermal treatment include the ease of handling the finished product, improved hygienic status of the feed, and reduced anti-nutritional factors. Besides the mechanic forces of processing, feed is also exposed to heat and steam as conditioning procedures. The amount and duration of heat and moisture applied while processing feed can have a significant effect on the availability of crude protein, amino acids, starch, fat, vitamins and feed additives. The effectiveness of feed processing on nutrient digestibility is also determined by the ingredients and their thermolability. There is a tradeoff between the control of feed borne diseases and digestibility of nutrients. Treatment conditions which reliably reduce harmful micro-organisms may have an adverse effect on digestibility and performance. Short time exposure of the feed to high temperature improves the hygienic status of the feed with limited impact on nutrient digestibility.

Keywords

Broilers, nutrition, feed treatment, pelleting, extrusion, expansion, digestibility, performance, micro-organisms

Introduction

Commonly, poultry is fed a complete diet composed of all ingredients required for balanced nutrition. Depending on the production type and management system used, the macrostructure of mash feed is modified to a pellet, expandate, or extrudate. While laying hens are commonly fed mash, broilers are mostly provided with pellets. Several factors (particle size, particle number, particle shape, flowability, moisture content, etc.) affect demixing of a diet and allow for feed selection by the animal (Amerah et al., 2008; Axe, 1995; Löwe and Mohrig, 2013). Therefore, the beneficial effects of compaction and uniformity of the mixture are of great impact to the poultry industry. Furthermore, thermal treatment of the feed results in modification of proteins and starch, diminishes microbial contamination, reduces dust exposure in the processing plant and in the poultry houses and decreases feed wastage (Maciorowski et al., 2004; Lundblad et al., 2011; Behnke 2001; Peisker, 2006). The physical and thermal effects are confounded when the effect of pelleting and other mechanic procedures are compared under practical conditions. While poultry feed can be heat treated to increase its value by improving nutrient digestibility or by inactivating specific anti-nutritional factors, the nutritional value of some feed ingredients can also be lowered by the heating process (Jia and Slominski, 2010; Kilburn and Edwards, 2001; Moritz et al., 2002).

The following techniques for thermal treatment are most common in the poultry industry:

Pelleting

Pelleting of feed involves a mechanical process, where the application of moist, heat and pressure results in the agglomeration of individual particles into a product of defined shape, size and durability. Commonly, (steam) pressure is applied to the mash feed particles (conditioning), which is then moved into the heated pelleting chamber (Figure 1a; 1b). Once the feed enters the pelleting chamber, it is forced to leave the pelleting press through a metal die of various diameters. During this pellet formation, the feed can be exposed to high friction temperatures (Fairfield, 2003). Depending on the size of the blending screen, the pressure of around 10–20 N results in a final feed temperature of 80–90°C. The heated product exits the pelleting press in long strands, and is then cut to length, cooled and dried.

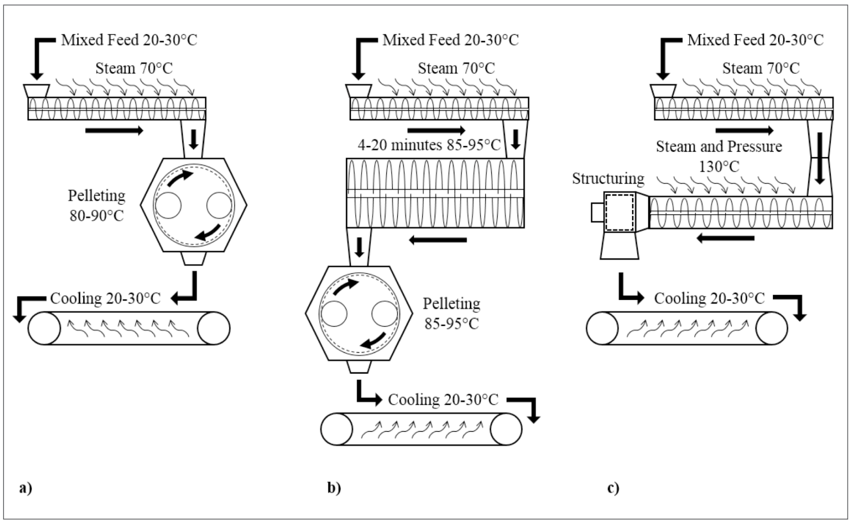

Figure 1: Scheme of pelleting: a) conventional, b) with long term conditioning, c) Scheme of expanding

The physical quality of the pellet is significantly affected by the cooling process, the length of cuts, temperature applied in the pelleting chamber, steam pressure and duration of conditioning, feed ingredients and diet formulation (Arshadi, et al., 2008; Fairfield, 2003; Lemme at al., 2006; Liu et al., 2013b). It has been estimate that the feed formulation and particle size determine up to 40% and 20 % the pellet quality; hence the major parameters of physical quality are already determined before the feed enters the pelleting machine (Behnke, 2001; Figure 2). Wheat as a major feed ingredient is thought to be beneficial for pellet quality due to its relatively high protein and gluten content, while being relatively low in fat compared to corn (Arshadi, et al., 2008; Denstadli et al., 2010). Pellet durability is predominantly influenced by steam added into the conditioner. Steam pressure, steam saturation and steam temperature are the major parameters of this treatment (García-Maraver et al., 2011; Jensen, 2000). Physical advantages of pelleting include ease of handling, reduced ingredient segregation, reduced feed wastage, and increased nutrient density (García-Maraver et al., 2011; Moritz et al., 2002).

The nutritional quality of pellets can be significantly influenced by the duration and temperature of heat exposure. In general, pelleting is used to improve nutrient digestibility, feed palatability and feed conversion ratio (García-Maraver et al., 2011; Jensen, 2000). Further details are outlined in the sections below "the impact of thermal treatment on nutrient digestibility". Increase in the average daily gain of broilers by 32% and feed to gain ration by 3% compared to mash feed have been reported by Jiménez-Moreno et al. (2016) and Engberg et al. (2002). Nutrient excretion can be decreased by 25%, depending upon pellet quality (Hancock and Behnke, 2001) Higher physical density of the pelleted feed enables higher feed intake and reduces time spent feeding. This leads to improved weight gain and feed efficiency. Therefore, an improved performance is common when broiler chickens are given pelleted diets (Abdollahi et al., 2013; Hamilton and Proudfoot, 1995; Lemme et al., 2006). With regard to the digestibility of the nutrients, the effect of pelleting can be highly variable and depends on many different factors which will be dealt with in the following section.

Figure 2: Factors influencing pellet quality include diet formulation, particle size, conditioning, die specifications, and cooling and the drying process. The pellet quality is evaluated by the pellet durability (ability to remain intact when handled), pellet hardness (maximum crushing load that a pellet can withstand without cracking), and the bulk density (biomass/volume). (Source picture: https://pixabay.com/photo-2615928/)

impact of conditioning varies with the feed ingredients used. For example, it has been shown that increasing conditioning temperatures decrease the body-weight gain and feed intake in broilers fed wheat-based diets (Abdollahi et al., 2010; 2011). Similarly, the negative impact of increased conditioning using temperatures above 80–90°C has been demonstrated by Cowieson (2005), when the production of pellets increased the viscosity of the diets. However, broilers fed corn-based diets conditioned at 60°C and 90°C had higher body-weight gain and feed intake than those fed on the diet conditioned at 75°C (Abdollahi et al., 2010). In agreement with these findings, broilers fed with corn-soybean meal pellets conditioned at 93°C significantly increased their feed intake, live weight gain and improved their feed conversion ratio (Cutlip et al, 2008).

Standard short-term conditioning for feed preparing before pressing (70°C)

Short term conditioning is used in nearly every method of feed compacting. Figure 1a demonstrates the schematic construction of a pelleting press with short term conditioning. The moisture of ingredients needs to be increased to form durable pellets. Steam applied in the conditioner provides a sufficient amount and quality of moist bridges between the feed particles and subsequently allows for binding mechanisms. The amount of saturated steam used to enhance the available moist varies between 1–13%. The use of saturated steam allows for simple temperature difference measurements: A moisture addition of 0.6–0.7% results in a temperature increase of the feed by 10°C. For example, if the starting temperature of 20°C is assumed, conditioning with 3% saturated steam will result in a feed temperature of 70°C in the press.

Long term conditioning (85-95°C)

One possibility to improve the hygienic status of the feed and the durability of the pellet is by applying long term conditioning. While short term conditioning allows mash to be exposed to 60–90°C for several seconds, long term conditioning can last more than 20 minutes (Fairfield, 2003). After the feed has been conditioned under standard procedures (short term conditioning), long term conditioning follows (Figure 1b). The most common steam condition temperatures range from 85–95°C. The mash is usually exposed to these temperatures between 4–20 minutes while being transported with an auger that allows homogenous mixing and subsequently uniform treatment of the feed (e.g. uniform steam injection, uniform heating of the conditioner, continuous speed of the auger). A continuously feed flow as well as any avoidance of clearance volume is essential for an acceptable product quality.

Steam conditioning significantly reduces the fine particle fraction, and increases pellet durability (Skoch et al, 1981). Due to the effect of heat and steam on various feed components such as non-starch polysaccharides (NSP) and subsequently the viscosity of final feed product, the

Expanding

Comparable to the pelleting process, the expander forces pre-conditioned mash feed through a die sieve of various diameters (figure 1 c). However, while the feed is subject to a shorter treatment time with a maximum dwell time of 3 seconds in the expanding chamber, the temperature that the feed is exposed to while being forced through the expanding chamber is comparably higher and reaches up to 130°C. Expanding combines hydrothermal exposure with mechanical shearing forces. Due to the more intense preconditioning status of the mash feed and the ability of adding steam and fluids directly into the expanding chamber, additional shearing forces push the feed through the machine (Abd El-Khalek and Janssens, 2010; Kaliyan and Morey, 2009). The following exposure to the ambient pressure results in additional shearing forces, reduction of the product moisture due to reactive flash volatilization, and cooling of the product to <100°C.

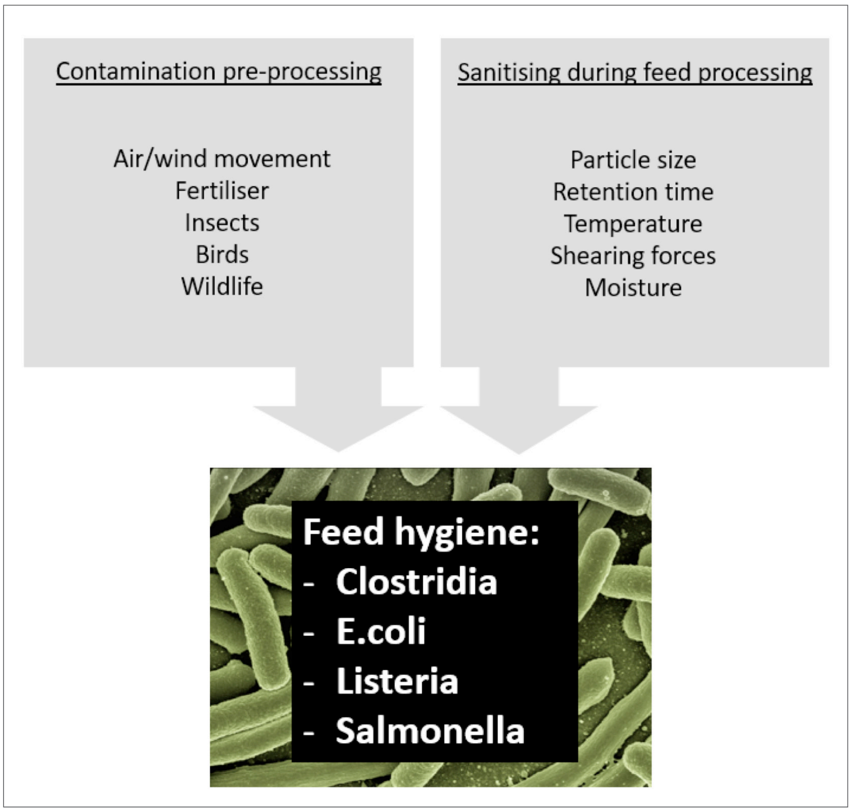

Figure 3: Factors influencing the hygienic status of feed
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Therefore, the structure of the resulting final product breaks up when leaving the expander and the expandate is characterised by a porous surface and lower density, compared to firmly pressed pellets (Kaliyan and Morey, 2009). While the unformed product needs to be cooled, an additional drying process in not required. The expandate can be fed directly or further be processed and served as crumbs, pellet, or granulated pourable feed.

The interaction between conditioning temperature and steam pressure and its influence on feed quality affects broiler performance directly. Due to the lower energy density of expandate and subsequently reduced feed intake, increased FCR and lower body weight has been observed in broilers (Smith at al., 1995; Lundblad et al., 2011). However, other studies show no significant differences in bird performance when comparing overall body weight and FCR of broilers and layers fed pellets and expandate (Boorojeni, 2014b; Peisker, 2006; Ruhnke et al., 2014).

Extrusion

Similar to pelleting and expanding, an extruder forces conditioned mash feed through a die of various sizes. Depending on the shape, diameters and distance of the feed delivering augers, the conditioned mash is exposed to various mixing and cutting forces. While higher levels of moisture, pressure, and heat are used for extruding, the end-product is of higher energy density and pressed into firm structures (Fancher et al., 1996; Heidenreich and Michaelsen, 1995). The use of multiple screw extruders is primarily of importance in the food industry and is capable of the production of specialised items, such as highly viscous foods (e.g. chewing gums, fatty products). Therefore, this method is relatively expensive and primarily used in the pet food or fish feed industry. However, extrusion has been shown to be extremely valuable in decreasing anti-nutritional factors in various legumes including lupines, fava beans, and peas, subsequently improving body weight gain, feed intake and feed conversion ratio in broilers (Hejdysz et al., 2015; Hejdysz et al., 2016; Rutkowski et al., 2016).

The impact of thermal treatment on feed hygiene (microbiota)

Poultry feed ingredients can serve as a carrier for a wide variety of microorganisms. Common modes of feed contamination include the transfer of soil by air movement, rain, mechanical agitation (use of manure as fertilizer, or insects). Temperatures above 71°C used for pelleting are known to reduce the bacteria load. Bacteria of concern to the poultry industry include Clostridia perfringens, Cl. botulinum, Listeria spp. Escherichia coli, and Salmonella spp.. The consequences of these pathogens on bird health and humans due to its potential of causing food-borne illness can be severe. For example, Cl. perfringens causes necrotic enteritis of the intestinal tissue, resulting in growth depression of affected birds and an estimated global economic loss of >2 billion US$ annually (Timbermont et al., 2011; Van der Sluis, 2000). The high prevalence of Cl. perfringens in broiler flocks can be explained by the high heat tolerance of its spores, surviving pelleting temperatures unaffected (Greenham et al., 1987). Salmonella spp. are one of the most common causes of human food borne illness (Tauxe, 2002). The amount of pathogens present in poultry feed, such as Salmonella enteriditis or E.coli, declines with increasing time of exposure to heat. The thermal death rate of salmonella in poultry feed can be predicted at varying time, temperature, and moisture (Himathongkham et al., 1996). For example, thermal treatment of feed with 93°C and 15% moisture for 90 seconds causes a 10,000- fold reduction of viable Salmonella spp. in vivo studies performed in broilers demonstrated that animals fed with pellets had significantly lower Salmonella spp. In their gizzards ($P < 0.01$) and caeca ($P < 0.05$), compared to broilers fed mash (Huang et al., 2006). Similarly, pellet-fed broilers of a different study had larger numbers of coliform bacteria and enterococci in the ileum but reduced number of C. perfringens and lactobacilli in the distal end of the digestive tract (caeca and rectum) compared birds fed with mash (Engberg et al., 2002). In agreement, increased feed processing temperature during pelleting, long term-conditioning and expanding led to an increase of lactobacilli in the crop and ileum of broilers, whereas clostridia and enterobacteria were unaffected (Boorojeni et al., 2014a). However, short term conditioning alone with subsequent pelleting has only shown to reduce the numbers, not to kill all pathogens reliably (Jones, 2011). The antimicrobial effect of pelleting needs to be homogenous and due to the uneven distribution of pathogens in the feed pelleting is not a reliable method to reduce the number of bacterial sufficiently (Jones & Richardson, 2004; Maciorowski et al., 2004). The antibacterial effect can be improved by using a higher mechanical force, such as a double press. In contrast, the short term but very intensive shearing forces in combination with the very high temperatures as provided by the expander results in a reliable profound hygienic status of the feed (Fancher et al., 1996; Maciorowski et al., 2004). Using the expander and various temperatures revealed that temperatures of at least 103°C are insufficient to kill pathogen bacteria and relevant spores reliably. Due to the very short duration that the feed is exposed to the high temperatures, only temperatures of 115–125°C result in a sufficient decontamination of the product by 10^5 to 10^6 colony-forming units (Fancher et al., 1996).

In summary, it can be concluded, that pelleting without any additional treatment is not a reliable method to improve the hygienic status of the feed while expanding feed at temperatures of >115°C can be considered as adequate. The success of thermal treatment depends on the on the intensity (temperature and moist), the duration of the treatment (retention time), as well as the mechanical shearing forces.

The impact of thermal treatment on nutrient digestibility

The impact of thermal treatment on nutrient digestibility of individual feed ingredients has been subject of many research studies. In general, hydrothermic or hydrothermic-mechanic feed treatment allows for a modification of nutrient digestibility including proteins, amino acids, and carbohydrates (Selle et al., 2012; Newkirk et al., 2003). The optimised application of thermal energy on the major feed ingredients is subsequently of highest importance for the feed quality and bird performance. While thermal treatment frequently improves digestibility of the nutrients, the heat application can result in chemical reactions such as the Maillard reaction between the aldehyde group of reducing sugars and the amino acids which significantly impairs nutrient availability (Lundblad et al., 2011, Amezcua and Parsons, 2007; Newkirk et al., 2003). The extend of the Maillard reaction reduces commonly the digestibility of heat labile amino acids such as lysine, arginine and threonine (Newkirk at al., 2003). Feed ingredients with high content of thermolabile amino acids such as canola meal should hence be heat treated with caution. Furthermore, it is known that heat treatment of feed can have a significant impact on digesta viscosity due to the varying amount of water soluble non-starch polysaccharides in various grains such as wheat and barley (Annison, et.al, 1991; Lundblad et al., 2011). The reduced protein availability can result in a depressed growth, reduced meat yield and increased mortality in broiler production (Amezcua and Parsons, 2007; Newkirk and Classen, 2002).

The impact of thermal treatment on crude protein and amino acid digestibility

In general, denaturised proteins are more exposed to digestive enzymes than proteins with an intact structure (Camire et al., 1990). Increasing conditioning temperatures from 65–80 and 95°C significantly enhances digestibility coefficients of amino acids in the proximal ileum and distal ileum in broilers diets (Anderson-Hafermann et al., 1992; Lui et al.; 2013a). However, these effects are mostly attributed to the physical denaturation of the intact protein, allowing its full exposure to enzymes, or the heat inactivation of anti-nutritive factors associated with protein inhibition (Abdollahi et al., 2013; Camire et al., 1990). So while moderate temperatures and short-term treatment showed beneficial or no effects, intensive thermal treatment significantly reduces amino acid availability due to a destroyed secondary structure and therefore diminishes the beneficial effects of protein digestibility seen at seen at lower temperatures (Panigrahi et al., 1996; Amezcua and Parsons, 2007). For example, autoclaving of diets for 40-60 min at 121°C and pressure of 105 kPa reduced amino acid digestibility and subsequently led to lower growth performance (Achinewhu and Hewitt, 1979; Fernandez et al., 1994). In another study, heat treatment of feed (85°C for 3 minutes) resulted in significantly reduced ileal nutrient digestibility of crude protein and amino acids in broilers compared to pellets or expandates (110°C for 3–5 seconds; 130°C for 3–5 seconds) (Boorojeni et al., 2014). The effect of heat treatment on crude protein and amino acid digestibility is also greatly influence by the type of crop, conditioning temperature and feed form which can be linked to the concentration and availability of disulfide bonds and sulfhydryl groups in the diet (Abdollahi, 2011; Selle et al. 2012). For example, increasing conditioning temperature decreased digestible protein and AME intakes in wheat-based diets but not in corn based diets (Adbollahi et al., 2010).

The impact of thermal treatment on carbohydrate digestibility

High processing temperature causes the destruction of the crystalline structure of starch granules which is called gelatinisation. Starch gelatinisation significantly improves carbohydrate digestibility especially in young animals which are lacking endogenous amylase activity (Bjorck et al., 2000; Holm et al., 1988; Kishida et al., 2001). Steam-pelleted diets have frequently shown to increase significantly starch digestibility coefficients in the proximal jejunum of broilers (Adbollahi et al., 2011; Selle et al., 2012). The extent of starch gelatinisation is widely influenced by temperature, shear force and the amount of moisture during feed processing. Starch gelatinisation occurs at 45–90°C and the temperature needed to initiate starch gelatinisation is inversely correlated with the water content of the feed. Moderate pelleting temperatures (65–85°C) results in gelatinisation of starch and cell wall destruction, both of which improve the availability of nutrients (Pickford, 1992; Svihus et al., 2005). When dry heat treatment (< 30%) is applied, more heat is needed to gelatinise starch. (Lund, 1984). Altering processing temperature and water availability has a significant impact in starch gelatinisation concomitantly with starch digestibility (Lundblad et al., 2011). However, prolonged heat treatment insignificantly reduces starch digestibility. Furthermore, the heating temperature at which starch will gelatinise is also influenced by the type of the crop. Starch in wheat will gelatinise at temperature range of 59–68°C while starch in corn will gelatinise at a temperature range of 63–72°C (Ingrid, 1997). For example, in wheat-based diets, increasing conditioning temperature decreased the ileal digestibility of nitrogen and starch while in corn based diets starch digestibility was unaffected (Adbollahi et al., 2010). Similarly, steam-pelleting at a conditioning temperature of 90°C improved significantly starch digestibility in red and yellow sorghum-based diets, but not in white sorghum-based diets. (Liu et al., 2013b). When comparing feed processed by various thermal treatments including pelleting, expanding, and extruding for broiler chickens, hydro-thermal processing increased total apparent starch digestibility, but due to reduced feed intake of the expanded and in particular of the extruded diets, only pelleting improved growth rate and feed utilisation (Lundblad et al., 2011). The reduced bulk density of expanded and extruded feed was held responsible for these effects. Additionally, extruded feed had the highest extract viscosity (Lundblad et al., 2011). Excess of starch gelatinisation can increase the solubility of the NSP which then increases the viscosity of the chyme in the gastrointestinal tract and lowering overall nutrient digestibility (de Vries et al., 2012). At high conditioning temperatures, wheat and barley have been shown to solubilize NSP and increase gut viscosity thus reducing broiler performance compared to maize and sorghum (Cowieson et al., 2005). As a consequence the addition of exogenous enzymes targeting NSP's can be up to six times more beneficial when applied to a thermal treated diet compared to mash (de Vries et al, 2012).

The impact of thermal treatment on fat digestibility

Fat in poultry diets is not only a source of energy but have other advantages including reduces dustiness and improvement of palatability. Feed processing methods such as expansion at 110- and 130°C, short and long-term pelleting have no significant effect on fat digestibility in broilers or layers (Boroojeni et al, 2014; Ruhnke et al., 2015). In contrast, oxidation of fat over time can affect odour and acceptance of a diet and the rancidity of fat can be influenced by the thermal treatment. For example, rice bran and full fat soy bean meal have antinutritional endogenous lipase and peroxidase enzymes that oxidize fats and oils. Heat processing of rice bran at 130–140°C immediately after milling and retaining the temperature at 97-99°C before cooling has been reported to stabilize oil for 30–60 days (Randall, 1985). Steam flaking of cereals can cause lipid oxidation. Oxidized fatty acid can react with certain amino acids and vitamins, making them inaccessible to the animal for digestion. Crystalline amino acids such as methionine and tryptophan are particularly susceptible to react with oxidized fatty acids.

The impact of thermal treatment on vitamins

Feed processing reduces the stability of vitamins which in turn reduces vitamin bioavailability. While all vitamins are heat labile, vitamin A, vitamin B7 (biotin) and vitamin B9 (folic acid) are the most sensitive to heat (Gadient and Fenster, 1994). Heat and steam accelerate most of the vitamin denaturing, with steam having the most influence. The influence of expander treatment on vitamins is significantly lower than pelleting (Kostadinovic et al, 2014; Jubero, 1999, Marchetti et al, 1999). The impact on vitamins due to expanding can therefore be neglected (Schai et al., 1991). This is summarised in Table 1. However, in order to protect vitamin E from the effects of unfavorable storing conditions (60°C and 80% humidity), pelleting and expanding seems to be more appropriate than no heat treatment, even though losses of 46–53% have been detected (Kostadinović et al., 2013). However, when investigating the stability of vitamin A in feed, its concentration decreased by 60–70% in untreated feed, while pelleted diets maintained 39–50% of their vitamin A content during a three month storage period (Kostadinović et al., 2014). Coating allows vitamins to be protected during the pelleting process (Gadient, 1994). If uncoated vitamins are used, an oversupply of vitamins should be integrated into the feed formulation to balance the expected losses (Broz and Ward, 2007).

Table 1: Vitamin losses (%) during pelleting and expanding

Vitamins	Pelleting (70°C)	Pelleting (90°C)	Expander (101-105°C)	Expander (111-115°C)
Biotin (B_7)	10	35	6	9
Choline	5	5	1	2
Folic acid (B_9)	5-20	45	6	9
Niacin	5	10	7	11
Pantothenic acid	10	20	5	8
Vitamin A	10	30-40	3	5
Vitamin C	40	85	2	4
Vitamin D_3	15	35	2	4
Vitamin E	10	15	3	5
Vitamin K_3	20	40	18	22
Vitamin B_1	15	50	4	8
Vitamin B_2	10	15	8	12
Vitamin B_6	10	30	6	9

Source: Charlton and Ewing 2007; Coelho, 1996 (Extracts)

The impact of thermal treatment on anti-nutritional factors

Thermal treatment is one of the most common methods of reducing the adverse effects of anti-nutritional factors in feed including enzyme inhibitors, haemagglutinins, plant enzymes, cyanogenic glycosides, goitrogens, phyto-oestrogens, saponins, gossypol, tannins, amino acid analogues, alkaloids, mineral- and vitamin binders.

Enzyme inhibitors occur naturally in plant ingredients such as trypsin and chymotrypsin inhibitors, amylase and elastase inhibitors, xylanase and plasmin inhibitors. Chymotrypsin activity in soy beans can be eliminated after 40 min at 80°C, 20 min at 90°C or 10 min at 100 °C, while trypsin inhibiting activity was abolished only after 90 min at 100°C (Armour et al., 1998). At 90°C, significant levels of trypsin activity persisted after 40 min of treatment, and the beans had to be heated for 90 min to eliminate any remaining inhibitory activity. Moderate pelleting temperature (65-85°C) deactivates enzyme inhibitors in cereals thereby increases enzyme activity (Saunders, 1975). Plant enzymes such as trypsin and urease activity are correlated to body weight and feed conversion ratio and can be destroyed by heat treatment of the feed (Ruiz et al., 2004; Foltyn et al., 2013; Anderson-Haferman et al., 1992). Especially legumes are rich in enzyme inhibitors, but also haemagglutinins and tannins. Traditional cooking, but also extrusion are reliable methods to decrease the activity of trypsin, chymotrypsin, α-amylase inhibitors and haemagglutinins significantly without reducing protein digestibility (Alonso et al., 2000). Soy beans and lucerne contain saponins which cause a bitter taste, foaming, and erythrocytolysis. In monogastric animals, such as pig and poultry, depressed growth, mainly due to reduced feed intake can be observed (Cheeke and Shull, 1985; Shqueir et al., 1989). Furthermore, unheated soyabeans contains heat-labile anti-vitamin factors that increases the requirement for vitamin B12 and others (Liener, 1980). Dehulling of the legumes decreased even further the tannin and polyphenol levels, allowing the extrusion process to be the most effective and reliable method (Alonso et al. 2000). Gossypol is known to be tolerated by poultry in high levels, but its adverse effects on egg yolk colour discourages its commercial use in layers and limited the inclusion rate (Aletor and Onibi, 1990; Aletor, 1993). Similarly, the presence of sinapine in rapeseed used to limit the use of this feed ingredient for the layer industry, as sinapine levels were associated with a fishy taint of the eggs, reduced feed intake, and reduced egg production. Studies on rapeseed involving a combination of chemical and hydrothermal processing with subsequent expansion and drying has demonstrated that it is feasible to decrease the sinapine content from 6152 mg/ kg rapeseed to < 50 mg/kg, and glucosinolate concentration, from 13.8 mmol per kg to 1.4 mmol per kg (Jeroch et al., 2001). Nevertheless, the inclusion of more than 22.5% untreated or treated rapeseeds significantly impaired egg production, feed conversion ratio, and egg weight (Jeroch et al., 2001). Other anti-nutritional factors such as cyanogenic glycosides, glycoalkaloids, coumarins, and amino acid analogues are of limited relevance in poultry, as their presence occurs predominantly in potatoes, solanum spp., sweet clover (Melilotus officinales), and other pastures which are usually not subject to a poultry diet.

The impact of heat treatment on enzyme efficacy

In commercial poultry feed production, dietary exogenous enzymes are included in feed to enhance nutrient digestibility by reducing anti-nutritional factors. For example, xylanases and β-glucanases have great efficacy in degrading β-glucans and arabinoxylans in rye, barley, wheat and oats based diets. Furthermore, the addition of phytase to poultry diets is known to effectively hydrolyse the bond between phosphorus and the phytate molecule, which increases phosphorus availability. However, heat treatment of feed can reduce the efficiency of phytase (Beaman et al., 2012; Slominski et al., 2007, Eeckhout et al., 1995). Exogenous enzyme thermostablity is a major concern in poultry feed processing as commercial diets are processed at >85°C while the limit for temperature stability for xylanase is 80–85°C (Silverside, 1999). Enzyme deactivation highly depends on the conditioning temperature and the conditioning time, with higher temperatures and prolonged conditioning times increasing inactivation (Beaman et al., 2012; Inborr and Bedford, 1994). On the other hand, increasing conditioning temperatures increases fibre solubility through excessive starch gelatinisation and enzyme β-glucanase supplementation linearly decreased digesta viscosity in temperatures between 75–95°C (Inborr and Bedford, 1994). This same study proved that increasing conditioning time from 30 seconds to 15 minutes linearly reduced and enzymes activity at any temperature from 75–95°C. Enzymes that are inherently thermostable can and should be protected by coating, thus preventing activity loss due to thermal treatment (Turner et al., 2007; Gilbert and Cooney, 2010; Rao et al., 1998).

Conclusion and implications

The commonly used treatments of broiler feed, pelleting, extrusion, and expansion combined with steam conditioning affect the performance in different ways. High feed density through compaction enables an increase of feed intake and reduced the time spent feeding, subsequently improving growth rate and feed to weight gain ratio. Pelleted and extruded feed have further advantages through reducing dust, avoidance of particle separation during transport, selective feed intake and reduced feed waste. The effect of feed treatment on the availability of nutrients, feed additives and hygienic status depends on a multitude of factors: level of pressure, temperature and moisture, duration of conditioning, type, particle size and thermolability of the raw components. Appropriate application of the procedure improves the digestibility of the main nutrients and reduces potentially harmful micro-organisms. Attention should be paid to possible tradeoffs between feed hygiene and improving nutrient digestibility. Conditions which reliably lead to a decontamination of feed can have negative effects on the digestibility of the main nutrients, vitamins and feed additives, such as enzymes. The use of high temperatures at short heat exposure such as the use of an expander allows to improve feed hygiene and control food borne diseases while limiting unwanted impact on nutrient digestibility. Coating heat sensitive feed ingredients such as vitamins and the use of heat stable enzymes can further reduce the adverse effects of thermal processing of feed.

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