EFFECTS OF THERMAL PROCESSING ON THE NUTRITIONAL VALUE OF FEED INGREDIENTS

Ferdinando N. Almeida, Oscar J. Rojas, and Hans H. Stein
Department of Animal Sciences, University of Illinois Urbana Champaign, Illinois, USA

1.- INTRODUCTION

Feed ingredients have been processed for many years with the objective of improving their nutritional value for livestock (NRC, 2012). Many of these processes involve the utilization of heat at different degrees (i.e., temperature, time), which aim at deactivating anti-nutritional factors (e.g., protease inhibitors) and in some cases improve the utilization of starch through gelatinization. Thermal treatments, however, may also cause destruction of other nutrients, which include, but are not limited to, amino acids (NRC, 2012). Among thermal treatments are extrusion, expansion, pelleting, and drying of feed ingredients. Because of the different processes that feed ingredients are exposed to and also because of their different nutritional composition, it is important to understand how thermal processing affects the nutritional value of different feed ingredients. Thus, the aim of this publication is to review the beneficial effects of thermal processing and to provide information about the negative effects of thermal processing on the nutritional value of feed ingredients.

2.- BENEFICIAL EFFECTS OF THERMAL PROCESSING

Diets for pigs may be supplemented with field peas, but because field peas contain antinutritional factors such as tannins and protease inhibitors, extrusion may be used to inactivate these antinutritional factors (Stein and Bohlke, 2007). It has been observed that extrusion of field peas fed to growing pigs improves the apparent ileal digestibility of crude protein, most amino acids, starch, and energy compared with field peas that were not extruded (Stein and Bohlke, 2007). Extrusion may also increase ileal digestibility of dry matter in corn fed to growing pigs (Muley et al., 2007). While an improvement in amino acid digestibility due to extrusion is attributed to degradation of protease inhibitors, the beneficial effects of extrusion on the utilization of starch and energy may be that extrusion creates an "ideal" environment for gelatinization. Moisture and heat are the 2 main factors necessary to gelatinize the starch. The hydrogen bonds in the crystalline region are resistant to water uptake from the starch granule, but when they break down in the presence of moisture and heat, this leads to an expansion of the starch granule (increased area) due to the absorption of water (Wiseman et al., 2001; Liu, 2011) and the amylose units will exude because of swelling of the granule. At 60ºC, starch begins to lose its physical properties such as organized granule structure and birefringence condition, and the starch gelatinization is complete when 98% of birefringence is lost (Wiseman et al., 2001). The temperature to produce gelatinization of starch is unique among different sources of starch. In corn, gelatinization occurs at 62-72ºC, in barley at 59-64ºC, and in wheat at 65-67ºC. During gelatinization of starch, the amylose part is released from the granule (reduction of the crystalline region), which increases the viscosity of the granule (Liu, 2011). This may also increase digestibility of the starch and gelatinized starch is more vulnerable to digestive enzyme degradation (Hancock and Behnke, 2001; Wiseman et al., 2001).

The digestibility of dry matter, organic matter, and fat is increased by pelleting of diets fed to weanling pigs, and this is accompanied by an increase in average daily gain and feed efficiency (Xing et al., 2004). The reasons for these improvements in digestibility and growth performance may be related to changes in physicochemical characteristics of nutrients such as starch, and may also be a result of reduced feed wastage (Richert and DeRouchey, 2010; NRC, 2012). It has also been observed that pelleting improves the digestibility of organic matter, protein, energy, ash, and digestible energy in diets fed to growing and finishing pigs (O'Doherty et al., 2000).

3.- NEGATIVE EFFECTS OF THERMAL PROCESSING

The concentration and digestibility of amino acids in feed ingredients and diets may be reduced due to thermal treatment of feed ingredients (Martinez-Amezcua et al., 2007; Boucher et al., 2009). Distillers dried grains with solubles that were oven-dried at 50, 75, or 100°C had reduced concentration of reactive lysine (Pahm et al., 2008). When autoclaving distillers dried grains with solubles for 45 min at 120°C, the digestibility of amino acids was reduced, especially that of lysine (Martinez-Amezcua et al., 2007), and it was suggested that the reduction in the digestibility of amino acids other than lysine was a result of the formation of Maillard reaction products that interfered with the absorption of other amino acids. Maillard reactions start with the condensation between an amino group of an amino acid or protein and a carbonyl group of a reducing sugar under certain conditions of temperature and moisture such as during extrusion and pelleting. Lysine is an essential amino acid that has an □-amino group that easily condenses with the carbonyl group of a reducing sugar (Nursten, 2005), and thus lysine is the amino acid most affected by Maillard reactions. Thermal treatment of whey protein in the presence of lactose at temperatures that ranged from 75 to 121°C also caused a decrease in the availability of lysine from 75 to 45% (Desrosiers et al., 1989). Feeding broiler chicks a diet containing high quality soybean meal or heat damaged soybean meal, it was observed that chicks that were fed the heat damaged soybean meal had a decrease in final body weight, average daily gain, average daily feed intake, and carcass weight compared with chicks that were fed the high quality soybean meal (Redshaw, 2010). These negative effects of heat damage on performance, however, were partially mitigated by adding crystalline amino acids to the diets. The standardized ileal digestibility of lysine in soybean meal fed to pigs was reduced from 93% (non-heated soybean meal) to 89.3 and 84.2% when soybean meal was autoclaved for 15 and 30 min, respectively, at a temperature of 125°C (González-Vega et al., 2011). In another experiment, Cozannet et al. (2010) observed that the standardized ileal digestibility of lysine in wheat distillers dried grains with solubles was highly variable and that the samples with the lowest values for standardized ileal digestibility were darker and contained less lysine as a percent of crude protein than the samples with the greatest values for standardized ileal digestibility of lysine, thus indicating that color and lysine to crude protein ratio may be used as indicators of heat damage in wheat distillers dried grains with solubles. As observed by Stein and Shurson (2009) and confirmed by Cozannet et al. (2010), when feed ingredients are heat damaged, the concentration of lysine is reduced whereas the concentration of crude protein remains relatively constant. Therefore, the concentration of standardized ileal digestibility of lysine in wheat distillers dried grains with solubles fed to pigs may accurately be predicted ($R^2 = 0.86$) from the lysine to crude protein ratio (Cozannet et al., 2010). It has been observed that there is a positive correlation between the standardized ileal digestibility of lysine and the lysine to crude protein ratio, which further confirms the above theory (Kim et al., 2012). The effects of processing conditions of fish meal on protein digestibility by mink were also evaluated (Opstvedt et al., 2003). It was observed that protein digestibility was less in fish meal sources that were produced at higher temperatures (> 100°C) than in fish meal sources that were produced at lower temperatures (< 100°C). Cysteine and arginine have also been shown to participate in the Maillard reactions (Ledl and Schleicher, 1990). Thermal processing may cause oxidation of unsaturated lipids leading to formation of hydroperoxides (Meade et al., 2005). Hydroperoxidases may oxideze cysteine, thus, limiting its utilization by the animal. In feed ingredients that have been heat damaged to a higher degree, pre-melanoidins may also react with cysteine and arginine (Finot et al., 1990). Cysteine may also go through Strecker degradation reactions producing hydrogen sulfide, ammonia, and acetaldehyde (Mottram and Mottram, 2002). The products of these reactions serve as intermediates to the formation of aroma compounds, such as thiazoles and disulfides, which are associated with the Maillard reactions (Mottram and Mottram, 2002). The participation of arginine in the Maillard reactions resulting from heat processing is associated with formation of cross-links with lysine through imidazopyridinium bridges (Ledl and Schleicher, 1990).

Heat damage may also cause losses in vitamins as observed by Ford et al. (1983). Results from their research clearly indicated that storage of whole milk powder at 60 and 70°C causes a reduction in the concentrations of vitamins B6 and thiamine. At 60°C, however, the reduction is much less pronounced than at 70°C. These observations may be because at higher temperatures the Maillard reactions are favored, which was confirmed by an increase in lactulosyl-lysine (which is an intermediate of the Maillard reactions) as the concentrations of vitamins decreased (Ford et al., 1983).

4.- CONCLUSIONS

It is well recognized that feed ingredients need to be processed and that application of thermal treatments in various processing steps is necessary. These thermal processes improve the nutritional value of feed ingredients in many cases, but they also expose feed ingredients to the risk of overheating. There is ample evidence that heat damage to feed ingredients may reduce the nutritional value of feed ingredients, specifically the concentration and digestibility of most amino acids and crude protein.

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