The fate of nutritionally important components during processing of feed and the effects on animal performance

Philosophiae Doctor (PhD)
Trial lecture
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Overview

1. Introduction

2. Different processing technologies

3. Effect of processing on nutritionally important components

4. Effect of processing on animal performance

5. Conclusion
Introduction

- Compound feed is a mixture of raw materials and feed additives optimized to meet nutrient requirements for animals.

- Major advances in feed processing the past three decades.

- Shift from simple “grind and mix” strategy to hydrothermal processing.

- In Europe 80 – 90% of the compound feed is pelleted.

- Various thermo mechanical treatments have become common for pig, poultry and ruminant diets.
Introduction

- To predict the effect of processing on nutritional value of the processed feed is a challenge for the feed industry and it is of great economical importance.

- Feed processing involves particle size reduction, mixing, addition of heat, moisture and shear forces.

- Beneficial and detrimental changes in the physiochemical properties of the nutrients, and in the bioavailability of nutrients take place during different feed processing.
Nutritionally important components

- **Carbohydrates**
  - Starch
  - Nonstarch polysaccharides (cellulose, hemicelluloses, β-glucans and pentosans)

- **Protein**
  - Amino acids
    - Essential amino acids
    - Non essential amino acids

- **Fat**
  - Glyserol
  - Fatty acids

- **Minerals**
  - Macro and micro

- **Vitamins**
  - Water - and fat soluble

- **Enzymes**

- **Anti nutrients**

- **Various additives**
  - Coloring and taste agents

- **Water**
Main emphasis in this presentation

- Focus on starch, protein, amino acids, vitamins and enzymes and their changes during processing
Main emphasis in this presentation

- How does these changes affect pig, poultry and ruminants performance?
  - ADG, ADFI and G:F ratio
  - Nutrient digestibility and feed utilization
Different processing technologies
Feed processing

- Mechanical
  - Grinding
- Chemical
  - Alkali - / acid treatment
- Thermal
  - Drying
  - Toasting
  - Micronizing
- Hydro thermal
  - Conditioning
  - Cooking
- Thermo mechanical
  - Pelleting
  - Expansion
  - Extrusion
Feed processing

- Mechanical
  - Grinding
- Chemical
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  - Extrusion
A Typical Feed Mill Flow

Diagram

Intake

Storage

Dosing & Micro Dosing

Grinding

Mixing

Pelleting

Cooling

Dryer
Reduction of particle size will increase both heat and moisture adsorption.

Grinding of raw materials is needed to achieve a homogeneous mixing before further processing.

Hammer mill is commonly used in Norway.
Effect of mechanical processing on starch, protein and amino acid

- Mechanical processing disrupt cell wall structures which makes cell contents more accessible for digestive enzymes - may result in increased digestibility

- Starch:
  - Some starch granules in the mash will disintegrate during grinding
  - Some starch will be mechanically gelatinized during grinding (approx. 10%)

- Protein / amino acid:
  - Not much affected during the grinding process
Thermo mechanical processing

- Thermo mechanical processing involves pelleting, expansion and extrusion
  - Increase moisture content
  - High shear forces
  - Increase temperatures

- High – Temperature – Short - Time process = HTST
  - Expander
  - Extruder
# Thermo mechanical processing

<table>
<thead>
<tr>
<th>Processing</th>
<th>Temp, °C</th>
<th>Moisture, %</th>
<th>Shear</th>
<th>Retention time, sec</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelleting</td>
<td>65-90</td>
<td>Max 18</td>
<td>Moderate</td>
<td>20</td>
<td>All</td>
</tr>
<tr>
<td>Expander</td>
<td>90-130</td>
<td>Max 18</td>
<td>High</td>
<td>20</td>
<td>Cattle</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pig</td>
</tr>
<tr>
<td>Extruder</td>
<td>→150</td>
<td>Max 35</td>
<td>Higher</td>
<td>60</td>
<td>Petfood</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fishfeed</td>
</tr>
</tbody>
</table>
Effect of processing on nutritionally important components
Gelatinization of the starch

- Starch is built of glucose polymers amylose and amylopectin
- In cereals starch is stored in granules organised in a protein matrix
- Processing leads to disruption of the molecular and granular structure as a result of gelatinization
- Starch gelatinization depends on:
  - Type of starch
  - Processing parameters
  - Interactions with other components in the diet
## Starch gelatinization temperature (°C) ranges of various starch sources

<table>
<thead>
<tr>
<th>Starch source</th>
<th>Onset temperature</th>
<th>Final temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>58</td>
<td>64</td>
</tr>
<tr>
<td>Barley</td>
<td>51</td>
<td>60</td>
</tr>
<tr>
<td>Oats</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>Rye</td>
<td>57</td>
<td>70</td>
</tr>
<tr>
<td>Corn</td>
<td>62</td>
<td>72</td>
</tr>
<tr>
<td>Sorghum</td>
<td>68</td>
<td>78</td>
</tr>
<tr>
<td>Rice</td>
<td>68</td>
<td>78</td>
</tr>
<tr>
<td>Triticale</td>
<td>55</td>
<td>62</td>
</tr>
<tr>
<td>Waxy corn</td>
<td>63</td>
<td>72</td>
</tr>
<tr>
<td>Amylocorn</td>
<td>67</td>
<td>92</td>
</tr>
<tr>
<td>Potato</td>
<td>58</td>
<td>68</td>
</tr>
<tr>
<td>Tapioca</td>
<td>59</td>
<td>69</td>
</tr>
<tr>
<td>Horse bean</td>
<td>61</td>
<td>70</td>
</tr>
<tr>
<td>Faba bean</td>
<td>61</td>
<td>66</td>
</tr>
<tr>
<td>Pea</td>
<td>65</td>
<td>69</td>
</tr>
</tbody>
</table>

(Hoseney, 1998)
Gelatinization of corn starch

www.oregonstate.edu
Different thermo mechanical processing affect gelatinization

<table>
<thead>
<tr>
<th>Processing</th>
<th>Gelatinization of starch, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam pelleting</td>
<td>12-19%</td>
</tr>
<tr>
<td>Expansion</td>
<td>13-51%</td>
</tr>
<tr>
<td>Extrusion</td>
<td>80-100%</td>
</tr>
</tbody>
</table>

Zimonja, 2008
Resistant starch (retrogradation)

- Intensive processing and subsequent drying/cooling may result in reassociation of gelatinized starch and formation of starch that are resistant to enzymatic digestion.
Effect of processing on protein

- Temperature, residence time, moisture content and shear forces during heat-processing are the most significant factors affecting the extent of chemical modification of proteins.

- Feed processing can give either beneficial or detrimental effect on nutritional value of protein.
Positive effects of processing on protein

- Unfolding and a mild denaturation of proteins can make them more available for digestive enzymes and therefore improve the digestibility.

- Thermal treatment can inactivate protein-based nutritionally active factors by destroying the integrity of their structure and hence prevent their activities.
  
  - e.g., deactivation of protease inhibitors and lectins in plants.
Negative effects of processing on protein

- Reduced protein value by making the protein and amino acids indigestible in the small intestine
  - Heat sensitive amino acids: lysine, arginine, cysteine, serine, threonine, histidin, aspartic acid,
- Crosslinking reactions can occur between protein-protein, protein-lipid, protein-carbohydrate complexes which may be resistant to enzymatic hydrolysis
Maillard reaction

- One of the most known is the Maillard reaction, a non enzymatic browning and flavoring reaction mainly involving the ε-amino group of lysine, and a reducing sugar group such as fructose, glucose and pentoses.

- Favorable conditions for Maillard reaction are high temperature and high shear, also moisture content, pH and time is important.

- Negative for monogastrics, but is positive for ruminants because it can increase rumen bypass protein.
Maillard reaction

Maillard reaction can be divided into three stages:

- Early stage: no formation of coloured components
  - Probably reversible both analytically and enzymatically (no problems)
- Advanced stage: a variety of reactions leading to the production of volatile or soluble substances.
  - Risk of analytical reversible, but not enzymatic (big problems)
- Final stage: insoluble brown polymers are formed with no nutritional value
Effect of processing on vitamins and enzymes

- Native vitamins and enzymes are heat sensitive
- It is commonly added heat stabilized vitamin and enzyme products, which is more or less protected against intensive processing
- It is recommended to apply the heat labile vitamins and enzymes in liquid form after processing, post pelleting application, in order to avoid degradation
Loss of vitamins during processing

- Feed processing may inactivate vitamins
- Heat labile vitamins are vitamin A, B₁, K₃ and C

Average % loss of vitamins during pelleting at 70°C and 90 °C (Pickford, 1992)

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Pelleting at 70 °C</th>
<th>Pelleting at 90 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>B₁</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>K₃</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>85</td>
</tr>
</tbody>
</table>
## Loss of phytase activity due to processing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Phytase activity, IU pr kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated mash</td>
<td>405</td>
</tr>
<tr>
<td>Steam conditioning, 90°C, 120 sec</td>
<td>206</td>
</tr>
<tr>
<td>Steam conditioning, 95°C, 185 sec</td>
<td>21</td>
</tr>
</tbody>
</table>

Skiba et al., 2001
Effect of processing on animal performance
Monogastric digestion

- **Pigs and poultry**
  - Single stomach
  - Poultry: gizzard mechanically breaks down the feed
  - Enzymatic digestion occurs in the small intestine
  - Nutrients need to be readily available for the digestive enzymes
Ruminant digestion

- Digestion of protein, starch and fibre, and production of microbial protein
- Unbalance in rumen digestion will negatively affect digestion and production of microbial protein
- Rumen bypass of starch and protein is important for animal performance
- For maximal energy utilization of starch and proteins should be digested and absorbed in the small intestine as glucose and amino acids, because digestion by enzymes are more effective than fermentation in the rumen
Particle size reduction - pig

- Fine grinding compared to coarse grinding:
  - improve nutrient digestibility and growth performance
  - coarse grinding results in reduced growth performance for piglets and grower finishing pigs compared to fine grinding

<table>
<thead>
<tr>
<th></th>
<th>Mash, μm</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Pelleted, μm</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000</td>
<td>800</td>
<td>600</td>
<td>400</td>
<td>1000</td>
<td>800</td>
<td>600</td>
<td>400</td>
</tr>
<tr>
<td>Dig, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>79.9</td>
<td>78.9</td>
<td>81.7</td>
<td>84.8</td>
<td>84.1</td>
<td>85.1</td>
<td>86.1</td>
<td>87.3</td>
</tr>
<tr>
<td>GE</td>
<td>77.6</td>
<td>75.8</td>
<td>79.6</td>
<td>84.1</td>
<td>83.3</td>
<td>84.6</td>
<td>85.7</td>
<td>87.5</td>
</tr>
</tbody>
</table>

Wondra et al., 1995
Particle size reduction can be negative to gut health – pig/poultry

- Fine grinding is also associated with increased incidence of gastric ulcers (Wondra et al., 1995)

- Fine grinding of the diet results in more keratinised stomach tissue and there are indications that fine grinding gives shorter villi:crypt volume in the small intestine

- Coarse grinding for poultry will satisfy the requirement for structural material for optimal gut and gizzard function
Pelleted diets of pigs result in an increased feed intake, weight gain and G:F ratio compared to mash control (Wondra et al., 1995; Johnston et al., 1999; Park et al., 2003)

Pelleting increased digestibilities of DM, N and GE by 5 – 8% compared to mash control

Pre-conditioning of mash prior to pelleting does not affect DM, OM, CP and crude fat digestibility compared to cold pelleting (Van der Poel et al., 1997)
Thermo mechanical processing - pig

- Protein, fat, fibre and organic matter was positively affected by fine grinding before pelleting compared to coarse grinding.
  - Improved accessibility of nutrients for digestive enzymes (Dirkzwager et al., 1998)
- Expanded feed improves digestibility of DM and gross energy compared to the mash control (Johnston et al., 1999)
- Thermo mechanical processing reduces particle size
  - Effect of grinding levelled out
Thermo mechanical processing - pig

- Higher viscosity for the extruder processed diet may have prolonged intestinal retention time, allowing more time for digestion and absorption of nutrients

Viscosity measured in the diets from 5-167 minutes after addition of pancreatin

Lundblad, 2009
Growth assay nursery pigs

<table>
<thead>
<tr>
<th>Item</th>
<th>Mash</th>
<th>Low temp</th>
<th>High temp</th>
<th>Expander</th>
<th>Extruder</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADG, g</td>
<td>425</td>
<td>440</td>
<td>429</td>
<td>430</td>
<td>445</td>
</tr>
<tr>
<td>ADFI, g</td>
<td>563</td>
<td>543</td>
<td>534</td>
<td>537</td>
<td>517</td>
</tr>
<tr>
<td>G:F, g/kg feed</td>
<td>759</td>
<td>810</td>
<td>802</td>
<td>802</td>
<td>860</td>
</tr>
<tr>
<td>Gel. of starch, %</td>
<td>9</td>
<td>14</td>
<td>15</td>
<td>24</td>
<td>77</td>
</tr>
<tr>
<td>Viscosity, cP</td>
<td>28</td>
<td>26</td>
<td>35</td>
<td>94</td>
<td>314</td>
</tr>
</tbody>
</table>

Lundblad, 2009
Standardized ileal digestibility in pigs fed processed feed relative to mash control

Lundblad, 2009
Thermo mechanical processing - chicken

- Broiler chickens showed reduced ADG and ADFI with expander conditioning and extruder processing compared to mash control (Lundblad, 2009)

- Processing may affect the antinutritive effect of soluble fibres, which increase viscosity of the gut content and thus reduce digestibility and nutrient absorption (Zimonja et al., 2008)
Thermo mechanical processing - chicken

- Reduction in ADG, ADFI and G:F with increased viscosity in the gastrointestinal content with steam pelleting compared to cold pelleting (Zimonja et al., 2008)

- Starch digestibility was higher for broiler chicken fed thermo mechanical processed feed (Weurding et al., 2002; Zimonja et al., 2008; Lundblad, 2009)
# Effect of processing on ADG and G:F relative to mash control

<table>
<thead>
<tr>
<th>Animal</th>
<th>Item</th>
<th>High temp</th>
<th>Extruder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piglets</td>
<td>ADG</td>
<td>100.9</td>
<td>104.7</td>
</tr>
<tr>
<td>Piglets</td>
<td>G:F</td>
<td>105.7</td>
<td>113.3</td>
</tr>
<tr>
<td>Chicken</td>
<td>ADG</td>
<td>115.6</td>
<td>87.5</td>
</tr>
<tr>
<td>Chicken</td>
<td>G:F</td>
<td>103.8</td>
<td>106.0</td>
</tr>
</tbody>
</table>

Lundblad, 2009
Particle size reduction - ruminants

- Small particle size give a rapid starch degradation which gives pH drop in the rumen
Reduced particle size will increase starch degradation and lowers rumen pH.
Rumen starch digestion differ among feedstuffs

Offner et al., 2003
Effect of expanded and pelleted barley and oats on rumen pH

![Graph showing rumen pH for barley and oats](image_url)
Thermo mechanical processing - ruminants

- Expander treatment has shown to have a potential to reduce protein degradation in the rumen (Prestløkken, 1999)
  - Probably due to introduction of internal cross-links in proteins
  - Result: protein digestion is moved from the rumen to the small intestine
- Important not to over-protect protein!
  - Overheating may reduce intestinal digestibility of protein
Utilization of the Maillard reaction to improve protein value

- Reaction between lysine and xylose used to reduce rumen degradation of protein and amino acids
- Rumen bypass of protein and amino acids is increased, although analytical loss of Lysine (17 %) was observed (Harstad and Prestløkken, 2000)
- Adequate availability of remaining lysine
Conclusion

- The fate of nutritionally important components are affected by feed processing
  - Modification of starch and protein
  - Losses of vitamins, enzymes and amino acids
  - Elimination of anti nutrients e.g. protease inhibitors
- Optimal processing vary between pig, poultry and ruminants
- Feed processing can be used as a tool to improve animal performance and economy in animal production
- It is important for the feed industry to know the specific effects of feed processing on nutritional value
Thank you for your attention!