Norwegian University
of Life Sciences

Master's Thesis 30 ECTS
Faculty of Biosciences
Department of Animal and Aquacultural Sciences
Trond Storebakken

Literature review on the influence of milling and pelleting on nutritional quality, physical characteristics, and production cost of pelleted poultry feed.

Stojan Milanovic
Feed Manufacturing Technology

Master thesis in Feed Manufacturing Technology

Norwegian University of Life Sciences

Faculty of Biosciences

Department of Animal and Aquacultural Sciences

Title:

Literature review on the influence of milling and pelleting on nutritional quality, physical characteristics, and production cost of pelleted poultry feed.

Supervisor: Professor Trond Storebakken

Student: Stojan Milanovic

Contents

Abstract

The major objective of poultry feed production is satisfying nutritional requirements, and conversion of macro and microelements into high valuable human food. The economic importance of poultry feed, becomes apparent when it is realized that 60-70% of the total production cost of poultry production is feed. For this reason, the efficient utilization of feed is extremely important in broiler production. The objective of this literature study was to review differences in energy consumption from different studies in the grinding and pelleting process, and to describe how the digestion of nutrients in poultry feeds are influenced by mash or pelleted feed.

Grinding is done due to necessity of mixing several ingredients with satisfying homogeneity. Grinding is done by two highly recognizable systems of production. First and most commonly used is hammer milling. The other type of grinding employed is roller milling. With involvement of 80% of raw materials with necessity for fragmentation, grinding is an important, basic operation in the feed mill. Pelleting is the most prevalent heat treatment in poultry feed production. The main reason why it is so important is that the process leads to agglomeration of smaller particles into bigger particles, the pellets. The grinding process can produce a wide span of particle sizes, depending on the specific needs for pelleted or mash feed. Mash feed provides the opportunity to produce feeds with low investment in feed processing equipment.

The reviewed literature showed that energy consumption is a highly relevant economical factor for the poultry feed industry. In observed studies from 3 different countries, the goal was to compare involvement of energy consumption in the final cost calculation of poultry feed. In experiment from Egypt, grinding process showed that is more suitable for feed production, up to 30% lower usage considering power consumption then pelleting. Study done in Norway documented that, when both grinding and pelleting are observed without any addition of enzymes or water, power consumption in grinding process is 10% less than in pelleting. And in third case from Bangladesh in intensive production, energy cost is the highest in the production of high quality pellets. But differences are small comparing to production of medium and low quality pellets, so it can be neglected because high quality pellets have higher demand %, and it is desirable for serious business giants.

Thus, the main criteria for evaluating optimal particle size in feed were both biotic and economic factors. Briefly, mash diets give greater unification of growth, lower mortality and requires lower use of energy than pelleted feed, making it more economical. Poultry has preferences for bigger particles size, so pelleted feed increases feed intake relative to mash. Pelleted feed also results in lower percentage of waste in feeding, has a better impact on animal respiratory system health, and is also easier to handle, transport and store. On the other side, pelleted feed is about 10% more expensive than the ones not pelleted. This is mostly due to higher energy consumption during production.

A major advantage of pelleted compared to mash feed is increased feed intake. Mash diets give greater unification of growth, lower mortality and requires lower use of energy than pelleted feed, making it more economical. Poultry has preferences for bigger particles size, so pelleted feed increases feed intake relative to mash. Pelleted feed also results in lower percentage of waste in feeding, has a better impact on animal respiratory system health, and is also easier to handle, transport and store. On the other side, pelleted feed is about 10% more expensive than the ones not pelleted. This is mostly due to higher energy consumption during production. Recommendations regarding optimum particle size have, however, been contradictory. The results from feeding trials and different experiments are confounded by a number of factors, including feed physical form, complexity of the diet, grain type, endosperm hardness, grinding method, pellet quality and particle size distribution. Each of these factors consists possibilities to influence on digestibility of poultry feed. From all these factors, grinding method and pellet quality have the highest influence on the poultry production results. The digestibility of poultry feed can be influenced by manipulation of the grinding screen size in the intensive production of high quality pellets.

The main conclusion based on the literature reviewed is that pelleted feeds seem to have more advantages than disadvantages, when compared to mash feed. However, opinions presented in the literature are divided, indicating that both pelleted and mash feeds defend their use in providing optimal nutrition of poultry.

Keywords: Grinding, pelleting, mash feed, pelleted feed, energy consumption, poultry, gizzard

Acknowledgments

I wish to thank my supervisor professor Trond Storebakken for all advices and good words, especially positive energy and life guidance.

I would also like to thank to Ismet Nikqi and Dejan Miladinovic, for their patience and useful comments, and shared experience.

On the end, I would like to thank to my family and friends for their moral support and encouragement throughout my study.

1 Introduction

1.1 Historical development of animal feed

Until two centuries ago, not much attention was paid to animal nutrition. Monogastric animals were left to search their own feed, or they were fed often from by-products of food production and household wastes. With mechanization of agriculture and increase of production efficiency during the 19th century, cultivation and use of agricultural products for animal feed became increasingly common (Đorđević and Dinić, 2011).

In the first half of the XX century farm animals were fed with high quantities of grains, with small amounts of protein (Đorđević and Dinić, 2011). Over time, research in animal nutrition progressed facilitated more precise definition of the composition of the feed. Mixing the ingredients to tentatively satisfy nutrient requirements became common (Ewing, 1951). Modern era of poultry farming is characterized by well-organized production. Under these conditions, nutrition has a crucial influence on the utilization of feed and the quality of the animal products (meat, eggs). Thus, nutrition is also pivotal for the economy of production (Đorđević et al., 2009). New breeds of domestic animals with higher productivity also demand proper and controlled diets to allow them to express their genetic potential (Đorđević et al., 2009). These changes in poultry production have set new requirements in terms of preparing feed for the animals. These improvements have resulted in feed production gradually moving towards fully satisfying the nutritional needs of animals, at least cost.

The objective for this thesis work is to review relevant literature with focus on a key area in processing pelleted feed, namely particle reduction in pelleted and mash feed for poultry. Another important part of this review was to explain how different particle size is influencing animal growth and health. Finally, this thesis gives aims at summarizing the published information into which factors are most important for obtaining cost-effective production of poultry feed.

2 Literature review

2.1 Feed for poultry

Industrially produced complete feed for poultry contains a high number of ingredients with demand to be homogeneously mixed. In order to achieve that, most of the ingredients in the feed mixture needs to be grinded. Grinding enables homogeneous mixing of raw materials (Behnke, 1996; Koch, 1996). This reduces stratification, and facilitates pelleting. Fragmentation also increases the surface area of the mixture of ingredients, thereby facilitating efficient digestion (Behnke, 1996; Koch, 1996). For this reason, fine grinding is regarded as a key factor for rapid growth in poultry. However, the vulnerability of modern, genetically improved poultry is increasingly recognized, and too fine grinding can both cause health problems and decrease growth of vulnerable poultry (Taylor and Jones 2004; Svihus, 2011).

The gizzard of poultry is equipped with powerful muscle, whose contractions lead to the fragmentation of feed particles (Svihus, 2011). The presence of large particles stimulate activity and development of gizzard. A well-developed gizzard increases volume and capacity of the digestive tract, and leads to longer retention time of digesta in the stomach (Svihus, 2011). This contributes to higher utilization of nutrients and lower the pH of the material in the stomach (Duke, 1992). Thus, it is also reducing the risk of coccidiosis (Cumming, 1994), and leads to the destruction of pathogenic microorganisms potentially present in the feed (Engberg et al., 2002). The gizzard has the ability to completely fragment coarse particles (Hetland et al., 2002). This fragmentation doesn't affect the speed of feed passage through the gastrointestinal tract (Svihus et al., 2002). This suggests that grains can be coarsely grinded, both leading ito a reduced nenergy consumption and increased capacity of the mill (Svihus et al., 2004b).

In modern rearing of poultry, mixtures are mainly used in pelleted form after mixing (Fahrenholz, 2012). Pelleting is an agglomeration process of feed ingredients under pressure, humidity and heat, the agglomerates form of rollers, or pellets (Skotch et al., 1981). Use of pelleted feed, improves productivity of poultry, especially faster growth and improved feed conversion compared with the use of powdered feed (Calet, 1965).

The pelleting process results in nearly complete conversion of coarse particlesinto fines. There were attempts of coarser grinding of poultry feeds, where the cereal mixture increase the proportion of large particles in the pellet. Thus, experiments conducted by Hetland (2003) and Svihus et al. (2004a) have shown that in extreme cases particle size before pelleting is extremely important. They have shown that when using coarsely grinded wheat in pelleting, the pellet press didn't grinded the coarser particles completely. This suggests that, the corn should be grinded coarser (by roller mill), than what is seen with the hammer mill (Đorđević et al., 2009) if the goal is to increase the amount of large particles in pelleted mixture.

2.2 Grinding

Grinding is necessary for mixing ingredients with a high level of homogeneity in the mixture. . Thus, grinding represent one of the basic operations in feed manufacturing production. More than 80% of the raw materials used for the production of animals, requires grinding (Đuragić et al., 2002). Grinding is done, above all, for all kinds of cereals, and by-products from agriculture and feed industry (meal, cake and mineral nutrients) (Đuragić et al., 2002). The structure of grinded product, whether the focus is on the individual components or finished mixtures, must meet the physiological requirements of the animals (Đorđević and Dinić, 2011). The finer the particles are, the greater is their specific surface. This allows the digestive enzymes to perform hydrolysis efficiently (Đuragić et al., 2002). The digestive systems of different animal species have different capacity for digestion, and require different degrees of fragmentation (Đuragić et al., 2002). Also, within the same animal species, there are different needs in terms of the degree of fragmentation, depending on the age of the animal. Cattle and sheep have a long and complex digestive system and feed particles don't have to be small. The degradation of starch in the stomach of these animals should be as low as possible for the sake of antagonizing rumen acidosis, and coarse grinding, to particle size is half or a quarter of the grain is recommended (Ziggers 2001). Pigs have a shorter digestive system, and need more fragmented feed. Poultry has a short but complex digestive system, facilitating use of coarser grinded feed compared to pigs (Sredanović et al., 1997; Ziggers 2001; Đuragić et al., 2002; Koch, 2002).

In addition to the physiological requirements of animals, the particle size is important for optimum performance of the technological operations such as mixing, pelleting, expanding and extruding (Wild, 1992). Grinding facilitates mixing of various components of the mixture and contributes to greater stability of the mixture, due to lower propensity towards layering of the various components (Koster, 2003). Fine grinding results in greater specific surface area of particles, causing the material to absorb a higher amount of water during conditioning (Koster, 2003). Thus, fine grinding will increase the degree of starch gelatinization, allowing better linkage of particles in the pellet. Good pellet quality, thus, is dependent on fine grinding, also because it reduces air space between the particles, and facilitates tight contact between particles in the pelleted feed (Koster, 2003).

Grinding of the different feed components can be done by using different types of mills. However, hammer mill and roller mill are most commonly used (Ziggers, 2001).

Table 1. Comparison of a hammer mill and roller mill (Wild 1992)

Characteristics	Hammer mill	Roller mill
Particle size	Small to big	Medium to big
Span of particle sizes	Wide	Narrow
Specific energy consumption	High/very high	Low
Heating	Substantial (10-15^{0}C)	Low (4^{0}C)
Aspiration	Needed	Not needed
Handling	Simple	Complex

2.3 Hammer mill

The hammer mill (Fig. 1), consists of a steel frame where rotor is placed. The rotor has several rows of narrow, steel hammers, with two possible setups, fixed or free hanging (Svihus, 2009, HFE 305 course). The hammers can be fixed both to the upper and lower ends (Svihus, 2009, HFE 305 course). The distance between hammers, placed in the same order, are determined by the dimensions of differential rings. The number, length, width, and strength of hammers depends on the type of material to be grinded and targeted degree of granulation (Koch, 2002, Kersten et al., 2005).

The grinding chamber is limited by a steel screen. Sieves with different hole sizes determines the size of the granulate (FAO, 2013). One or more magnets must be incorporated to prevent metal particles in the chamber of the feeder system. Metal particles can damage to the hammer mill. Furthermore, they may create sparks that can cause dust explosion (FAO, 2013). Below the sieve is a hopper for milled product. Milled material can be carried from the mill by conveyors or pneumatic transporters (Kersten et al., 2005).

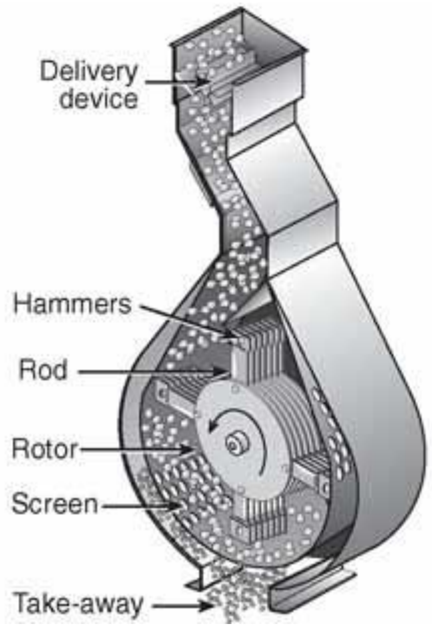

Figure 1. Basic hammer mill (Koch, 2002)

Grinding in the hammer mill is induced by two forces, impact force and friction. When material enters the milling chamber, the hammers are moving at high speed and fragment the particles whom are smashed (Svihus 2009, HFE 305 course). The hammers also send particles to the surface of the sieve and shock plate. The high speed of the hammer results in a curtain of material creating a ring between the tip of the striker and the screen surface (Svihus 2009, HFE 305 course). Particles near the hammer accelerate, and the particles in the outer parts of the rings slow down by sieve. Layers with different speeds of particles are then formed (Svihus 2009, HFE 305 course). Particle velocity is decreased as the layer approaches the sieve, and when the output speed is sufficiently low, they pass through the openings of the sieve if their diameter is smaller than the holes in the screen (Svihus 2009, HFE 305 course). Friction becomes significant when particles have contact with the screen surface. This leads to increased fragmentation and shaping of the particles. (Svihus 2009, HFE 305 course). Thus, the particles have a more regular, spherical shape when subject to hammer milling than when using other methods of milling. The particles leave the milling chamber, upon reaching a critical output speed. If the velocity of the particles near the sieve is higher than this critical output speed, they will continue their circular movement. This leads to excessive grinding, prolonged time for milling, and heating of the materials. (Miladinovic D., Pers. comm.). Exit of particles is supported by aspiration of air, which attracts enough grinded particles through the sieve openings. Particles that passes through a sieve and fall into the receiving hopper are then transported either mechanically (worm or chain conveyors) or pneumatic transport (Heiman, 2005; Kersten et al., 2005; Anderson, 2007). Different factors are influencing on fragmentation, such as type of materials that needs to be grinded (physical-chemical, and structural and mechanical properties), and also grinding parameters (Svihus 2009, HFE 305 course). With the increasing strength and elasticity of the particle, grinding capacity decreases and energy expenditure increases (Kersten et al., 2005). Important parameter of grinding at hammer mill is the circumferential velocity of the striker. When the speed increases, particles that have already been grinded to desired size, they have less time to go out through the sieve holes, because they will quickly come to next hammer. This causes excessive fragmentation and longer retention of material, hence lower capacity of the device and higher specific energy consumption (Svihus 2009, HFE 305 course). It is therefore, highly important to set extensive optimal speed of the hammers. In the case of too high fragmentation of materials, it is economically favorable to reduce the extensive speed of the striker than to increase the size of mash screen (Svihus 2009, HFE 305 course). For maximum energy savings, it is recommended to go for minimum value of the rotational speed, which achieves a satisfactory degree of fragmentation (Ruetsche, 1989).

2.3.1 Factors affecting grinding result by the hammer mill

The type of cereal matters when it comes to grinding efficiency. It is proven that more fibrous cereals are grinded less efficiently, than other fragile cereals. Most common cereals which are used in feed production, and where the grinding efficiency declines in this order are: Corn→Wheat→Barley→Oats (Svihus 2009, HFE 305 course). Grain's level of moisture has a big influence on the final grinding result. Thus, high moisture level in the grains can result in higher energy consumption during grinding. Moreover, technical properties of hammer mill are significantly influencing on the grinding efficiency. For instance, the number of hammers (usually 4-8 rows of hammers) is proportional with through output rate, on the other hand is inversely proportional with particle size (Svihus, 2009, HFE 305 course). This means that increased number of hammers will result in higher grinding speed but finer particles. Grain particles, thus, are likely to get higher number of impacts as the number of hammers is increased. Hammer speed should not be higher than a certain limit. Increased or decreased speed may lead to deviations from targeted particle size (Svihus 2009, HFE 305 course).

However, it is possible to control grinding by adjusting hammers speed. For example, for more fibrous cereals high tip speed should be selected (Niqki, I., Pers. comm.). On the other hand if the goal is to get coarser particles, then inevitable solution is to decrease the velocity of hammers. Wear of hammers and screen effect on the particle size and energy consumption. As, wear increases, particle size and capacity decreases, and energy consumption increases (Niqki, I., Pers. comm.).

Another factor affecting the grinding result is the distance between hammers and screen (Niqki, I., Pers. comm.). Thus, closer distance results in finer grinding. Usually the distance is set to 12-14 mm. But if the diameter of mill is larger, the particles will be coarser. The diameter of screen holes has proportional relation with throughput rate and particles size (Niqki, I., Pers. comm.). The air suction system is a vital part of the horizontal hammer mill. Speed of the air suction out of the mill is an important factor affecting grinding efficiency and the grinding result (Svihus 2009, HFE 305 course). Generally, high air suction will boost grinding speed, and promoting the flow of particles through the chamber, and likely will reduce the energy consumption of the hammer mill. In addition to that, air suction will result in more uniform layout of particle on the way out (Niqki, I. Pers. comm.). It occurs because, the finer particles will be sucked and separated from normal particles. Air suction can also be important to prevent the increase of temperature inside the grinding chamber. Feeding of the hammer, is one of the most important phases affecting grinding efficiency. Even if the hammer mill is well-matched to its tasks and well-maintained, it can cause problems, especially if it is not properly fed (Gill, 2013).

Therefore, responsibility is high when it comes to deciding upon the feeding device for the hammer mill. According to the feeding device expert Alles (2003), there are two criteria vital for the performance of feeding device. First one says that feeder must provide a “uniform curtain” of material for the grinding chamber of hammer mill and second that this curtain of material must be fed “full width of” across the hammer mill chamber (Kvanne and Phillips, 2003). Poor uniformity in the feeding of hammer mill can cause stability problems, excessive wear, reduced capacity, higher variations in particle size and heating (Kvanne and Phillips, 2003).

2.4 Roller Mill

Roller mills are not widely used as hammer mills in the feed industry. But they still can be convenient for particular grinding cases. From personal communication with Nikqi I., and Miladinovic D., at NMBU Centre of Feed Technology, I have learned about typical advantages of roller mills, such as energy efficiency, uniform grinding result, low noise of operation, and low dust generation. But also higher maintenance cost, poor result in grinding of fibrous cereals and mixed grains, can be considered as disadvantage of roller mills Niqki, I., Pers. comm.). Usage and exceeding full potential, is expressed when it deals with friable products that have uniform shape and size. They are not expressing relevant results when it comes to dealing with mixed grains (dissimilar shape and size). They do not alter size of fibrous materials (Koch, 2008).

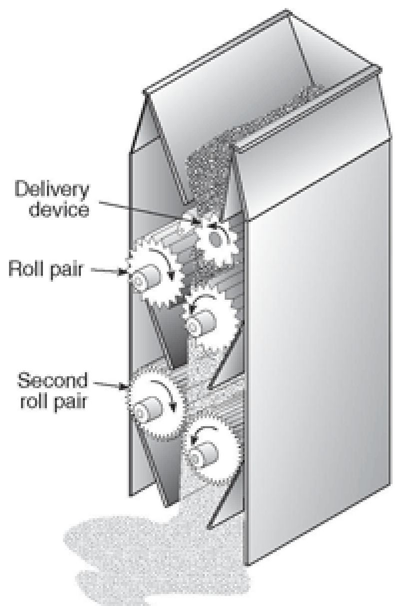

Figure 2. Roller mill with two pairs of rolls (Feed machinery 2017)

2.4.1 Basic roller mill

The main grinding principle in the roller mill is compression. The materials from the delivery (feeding) device passes between one, up to three counter rotating pairs of rolls and are being squeezed. The rolls can rotate with equal or unequal speed. When there is a difference between two rolls' velocity, than shear and friction contributes to size reduction (Nikqi I., Pers. comm.). In each pair of rolls one roll is anchored in a fixed position but the other one can be adjusted in different ways. That type of design allows us to control the size of grinded particles (Nikqi I., Pers. comm.). Thus, there is possibility to adjust space between two rolls, and this will determine the particle size. However, it is also possible to adjust grinding properties by adjusting the speed of two rolls and choosing rolls with different corrugation patterns (Nikqi I., Pers. comm.).

2.5 Effect of grinding method on broiler performance

Broiler performance is not affected with grinding when diets with similar geometric mean particle diameter are compared (Nir et al., 1990). The geometric mean diameter, has the capability for accurately describing particle size distribution, but only when passage of particle size is normally distributed (Lucas, 2004). The result of hammer mill grinding is higher amount of fine particles than roller milling (Reece et al., 1985.

3 The pelleting process

The pelleting process is considered as the most prevalent heat treatment, when it relates to production of poultry feed. Agglomeration is the key for successful pellet production, where small feed particles are agglomerated into pellets (Abdollahi et al., 2012). A main objective is economic part where the focus is on feed efficiency and utilization of feed. Pelleting also directly affects and increases the feed intake, and thus growth performance (Abdollahi et al., 2012). During pelleting various chemical reactions such as gelatinization of starch and partial denaturation of proteins occur (Abdollahi et al., 2012). Gelatinization of starch is only modest. Nevertheless, denaturation of protein is taking vital role in enhancing utilization of protein and also to some extent of starch digestibility, mainly because proteinaceous enzymes inhibitors become inactivated (Abdollahi et al., 2012). However, "pelleting remains potentially aggressive process on the stability of exogenous feed enzymes and vitamins, leaving feed producers with major concern" (Abdollahi et al., 2012). In the terms of conventional pelleting process, "good pellet quality is usually obtained at the expense of nutritional quality" (Abdollahi, et al., 2012).

3.1 Important advantages of pelleting:

With mentioned facts above, it is necessary to inscribe a classification of important advantages of pelleting process according to its importance: Increased feed intake - (e.g. in broiler chickens), decreased waste – uniform shape prevents the animal to eliminate large or fine particles from feed (Jones et al., 1995). Birds fed with pellets spend less time and energy in the ingestion of feed, and also gaining more nutrients per every unit of expended energy then the birds which are fed with mash diets (Jones et al., 1995; Vilarino et al., 1996). Some factors such as decreased particle size, improved palatability, and decreased microbiological activity stimulate increased nutrient density and digestibility (Jones et al., 1995). Also efficient transportation and less dust are regarded as important advantages of pelleting which are implemented through increase of the bulk density occurring in pelleting process. Some factors such as feed formulations, feed conditioning and grinding are considered as vital in the sense of pellet quality (Vilarino et al., 1996).

3.2 Important features of the pelleting

Description of pellet mill features:

Under general process conditions, the production goal is “perfect” pellet. “Perfect” pellet is reflected in characteristics, with cooking rate about 50%, level of moisture up to 16-17%, and with less usage of pellet binders, up to 2-3% (Svihus, 2009, HFE 305 course). Fines in the pelleted product is acceptable up to 5% (Kenny, 2007).

Changes in diet composition may directly affect pellet durability. Combining different raw materials with higher binding capabilities (wheat, barley), as well as the use of pellet binders such as lignosulfonate will have positive influence on pellet durability (Kenny, 2007). “The particle size of grinded feed materials has significance influence on pellet quality” (Ziggers, 2010). The large particles can reduce pellet strength. As the particle size is reduced to the small finely grinded particle, leading to increased surface area, thus promoting adhesion of the particles. (Ziggers, 2010).

The two main indicators in the pre-conditioner, which should be monitored carefully before pelleting, are steam quality and retention time. “Steam quality determines the temperature and moisture profile inside the conditioner” (Ziggers 2010). Wet steam “transfers” the heat less efficiently than saturated steam, because of lower enthalpy of evaporation. Wet steam may also lead to uneven moisture distribution in the mash, which can in the end result in “choking” or slipping of the pellet die (Kenny, 2007). Increased retention time in the conditioner may also increas starch gelatinization cause protein denaturation (Kenny, 2007). Both of these reactions will occur simultaneously and have positive influence on pellet quality.

4 Chemical composition of pelleted material

Chemical composition of pelleted material has a large impact on the quality of pellets, as a result changes of certain chemical substances that occur during pelleting process (Thomas et al. 1998). The intensity of these changes depends on the conditioning parameters (Moran, 1989) as well as the pelleting parameters (Van der Poel, 1994). Chemical components of the feed are classified into starch, proteins, sugars, fibers, fats, inorganics, and water (Thomas et al., 1998).

Starch is the main nutrient in cereals, and it's vital as energy source in animal nutrition (Zimonja and Svihus, 2009). Gelatinization of starch occurs during the thermal treatment in the presence of water. This is a process that involves structural changes, due bonding of gelatinized starch (Svihus and Gullord, 2002), and also improves pellet quality (Heffner and Pfosten, 1973). The mechanism where starch contributes to the binding is not completely understood. The presence of water is a prerequisite for gelatinization. The optimal ratio between water and starch is 0.3: 1 for obtaining good gelatinization (Lund, 1984). Complete the gelatinization of starch, however, requires a ratio of water and the starch should be as high as 1.5: 1 (Wootton and Bamunuarachchi, 1979). Hydrolysis of starch is increased by addition of mechanical energy. Starch is, however, not fully gelatinized by pelleting, only cooked (Zimonja and Svihus, 2009). Amylose leaks out of amorphous regions but crystalline regions are intact in the granule (Zimonja and Svihus, 2009). This indicates that during the pelleting, water is the limiting factor for the complete starch gelatinization, due to the humidity of pelleted material is not higher than 17-18% (Svihus and Gullord, 2002). It is sufficient that the starch is pre-gelatinized on the surface of the particles to be effective as a binder (Thomas and Van der Poel, 1996). In addition to gelatinization of starch, protein denaturation improves the quality of pellets (Maier et al., 1999). Namely, the proteins in the pelleting process, under the effect of heat and friction, and in the presence of water, partially denature (Maier et al., 1999). This, and their adhesive properties positively affects the hardness and decrease abrasion of pellets (Wood, 1987; Thomas et al., 1997).

Power consumption increases due to higher friction in the channels of the matrix pellet press when simple sugars (mono and disaccharides) are present (Thomas et al., 1998). Sugars, however, have favorable effect on the quality of pellets. During the cooling process, mono and disaccharides recrystallize and establish solid-solid bindings (Friedrich and Robohm, 1982; Thomas et al., 1998).

Fibers (non-starch polysaccharides) are classified as water soluble and insoluble (Frohlich, 1990; Lo, 1990). This division is helpful in terms of explaining the operation of the pelleting process. Water soluble fibers (glucans, arabinoxylans and pectins) increase the viscosity of the pelleted material. Highly viscos materials, acts as a filler, and like that get surrounded by larger particles and fills the pores. This resultsin obtained firmer pellet with less abrasion (Thomas et al., 1998), and higher hardness. The porosity of the pellet is a main factor in determining the hardness (Rumpf, 1958; Ouchiyama and Tanaka, 1985). The fibers also have a dual role in water-insolubility, as they strengthen linking of the particles during the pelleting, and improves wrapping (Rumpf, 1958).

Due to their strength and elasticity, possible problem such as pressure drop may occur after the release of the pellets from the channel matrix. As a result, pellet structure may be negatively affected by elastic forces, hindering the structure of pellets (Thomas et al., 1998). The longer retention of material in the channel matrix (thick matrix, reducing the flow), the more the effect of elastic forces is neutralized, and allowing production of good pellet quality (Thomas et al., 1998).

Addition of fat in pelleted mixture reduces pellet strength and increases abrasion (Stark, 1994; Angulo et al., 1996; Briggs et al., 1999). Fat acts as a lubricant between the particles and the wall of channel matrix, and also between the particles themselves, ending with less friction and thereby lowering the pressure in the channel matrix. The result is increased rubbing of the end product (Kaliyan and Morey, 2008). The hydrophobic nature of fats also inhibits binding properties of other components, i.e. starch, protein and fiber (Thomas et al., 1997). Cavalcanti (2004) found that increasing the fat content above 6.5%, in a mixture based on corn and soybeans, adversely affected pellets quality. On the other hand, the addition of fat decreases energy consumption of the pellet press, and increases pelleting capacity, due to its lubricating effect (Walter, 1990).

5 Digestion in poultry

The digestive tract of poultry is significantly different from those of other monogastric animals. One of the peculiarities is the extension on the end of the esophagus - the crop, where material is retained between 3 and 15 hours (Jovanović et al., 2000). It also depends on the structure of feed (smaller particles lead to shorter retention time) and how hungry the chicken is (tt feed passes immediately to the craw and fills out the stomach in a hungry animal) (Jovanović et al., 2000). In the craw feed is moisturized, softened and swells, and digestion is initiated by saliva enzymes (Jovanović et al., 2000; Đorđević et al., 2009).

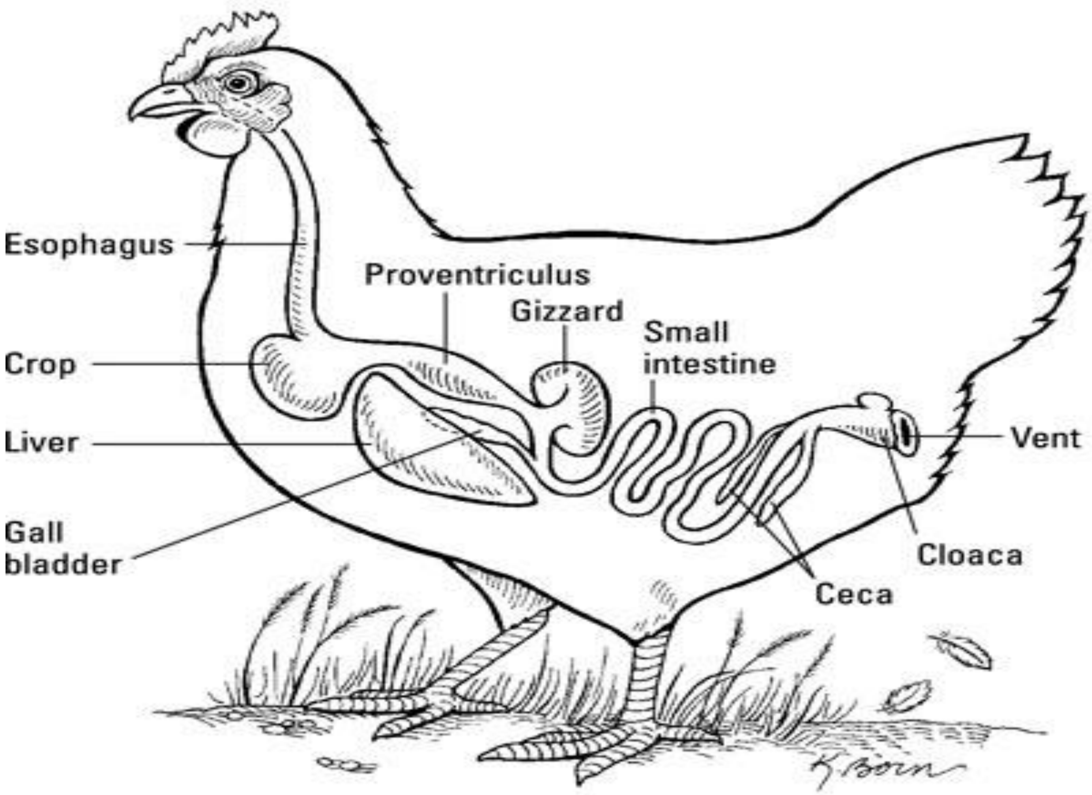

Figure 3. The digestive system of chicken (Dummies 2016)

The craw continues in the stomach, which consist of two organs: the glandular stomach (proventriculus) and the muscular stomach (gizzard) (Đorđević et al., 2009). On the mucosal proventriculus, there are openings which through whom glands that secrete pepsinogen, hydrochloric acid and rheum (Đorđević et al., 2009). This is the starting point of protein digestion, and separation of mineral substances from the complex compound feed. The muscular stomach supplies the powerful muscles and rheum membranes, and it’s thick and cornified, with transverse folds (Đorđević et al., 2009). , Highly efficient comminution of feed occurs in this part of the intesinal system duestrong muscle contractions. In this way, the gizzard replaces the chewing apparatus, which birds are missing (Đorđević et al., 2009).

From the gizzard, material (chyme) enters the duodenum where digestion continues under the action of the pancreatic enzymes and intestinal juice and gall (Đorđević et al., 2009). Pancreatic juice contains proteolytic, amilolytic and lipolytic enzymes that hydrolyze most of the nutrients in this section of the digestive tract (Đorđević et al., 2009). In the other parts of the small intestine, it completes the digestion of nutrients below enzymes of the intestinal juice, containing peptidase enzymes, amylase and maltase. Part chyme enters to two appendix, where the material is decomposed affected with present microflora (Đorđević et al., 2009).

5.1 Anatomy and Function of gizzard

Since the birds have no teeth, and disintegration of feed particles is necessary, these animals have specific organs, such as gizzard, adapted for grinding of feed (Svihus, 2011; Rodgers et al, 2012). The largest part of gizzard consists of two thick lateral muscles and two thin muscle, on the front and rear. With respect to the longitudinal axis of the gizzard, thick and thin muscles are asymmetrically deployed, and contractions result in fragmentation of feed particles (Svihus, 2011). The cycle begins with grinding of thin muscle contraction, in the opening of the pylorus and strong peristaltic contraction of the duodenum. Pylorus is a small opening at the end, exactly functioning as a gizzard sieve and not allowing the passage of too coarse particles to the duodenum (Svihus, 2011). Simultaneously with the contraction of duodenum, there is a thick muscle contraction in the gizzard, causing the amount of material to be pushed out into the duodenum, but also dragging new amount into proventriculus (Svihus, 2011). After relaxing, thick muscle contraction occurs in gizzard proventriculus, resulting in materials being driven out..

The entire cycle of described contractions, takes place four times in minute and it shredded material particles due to rubbing against the walls of gizzard and about each other (Svihus, 2011). Also it occurs during the contraction of thick muscles, while thin muscles transport material according to the zones of grinding between two thick muscle contractions (Duke, 1992).

Although proventriculus is a separate body which precedes the gizzard, it has small volume and it’s causing a short residence time of material (Svihus, 2011). Therefore, the bulk of decomposition of nutrients happens under the influence of pepsinogen and hydrochloric acid, which is secreted in proventriculus of gizzard (Svihus, 2011). In gizzard, contractions of the material are being returned to proventriculus in additional secretion of digestive juices in the same material (Duke, 1992). Therefore, the gizzard proventriculus, may be considered as unique whole. Mean residence time of material in proventriculus and gizzard ranges from 30 min to 1 hour (Duke, 1992). Larger particles must be fragmented to a certain critical size with ability to go through the pylorus and abandon the gizzard (Moore, 1999). According to a survey conducted by Ferrnado et al. (1987), the critical particle size is between 0.5 and 1.5 mm. Data from Hetland et al. (2002; 2003) and Amerah et al. (2008) indicates that the highest part of the particles that enter the duodenum, is less than 0.1 mm. According to research of Amerah et al. (2008; 2009b), with an increase in the share of large particles of mixture, result in highly increased volume of gizzard. Close up particles are selectively retained in the gizzard (Hetland et al., 2003) until the time of retention of small particles does not change with the change of the share of large particles (Svihus et al., 2002). Although, this indicates that the retention time of particles of different sizes is unequal, and mean residence time significantly increases under such conditions (Svihus et al., 2002). If the retention time of the standard commercial mixtures with small proportion of large particles is approximately one hour, then mean residence time of the large particles can go up to two hours.(Svihus, 2011).

The gizzard can regulate the amount of ingested feed and the flow of feed from craw. (Chaplin et al., 1992). In pig or human, stomach has a key role in regulation of feed intake, but in poultry that role has gizzard, or system gizzard / proventriculus, from where it sends a signal of satiety (Svihus, 2011). Even when the signal of satiety in modern broiler overpowers their large appetites, well developed gizzard can prevent overeating due to limited volume. (Ka et al., 2009; Cline et al., 2010). Overeating is considered as undesirable phenomenon in growing broilers (Ka et al., 2009; Cline et al., 2010).

5.2 Influence of the structure of the mixture on the development and functioning of gizzard

Digestive tract of birds can quickly adapt to the changes in feed composition (Klasing, 1998). Various studies of wild birds has shown, that due to the large variation in the composition of feed throughout the year, there is a change in the size of the small intestine and the cecum (Klasing, 1998). Gizzard particularly quickly responds to changes in the composition of feed, primarily to the changes in the structure of mixture (Farner, 1960).

After grinding and mixing process, particles are merged into the pellets in order to increase feed intake and to utilize technical characteristics of the mixture (Svihus, 2011). Already in the early parts of the digestive system, pellets are dissolved and macrostructure has no influence on the development of the gizzard. Thus, macrostructure can only increase the amount of ingested feed (Svihus, 2011). However, it exceeds to a finer pelleting of microstructure and of mixture, due to fragmentation of particles that occurs during the pelleting process (Svihus et al., 2004b). In the mixtures with high proportion of large particles is especially expressed (Engberg et al., 2002; Svihus et al., 2004b). Rapid development of gizzard is influenced by the increased share of large particles (Svihus, 2011). Thus, the Biggs and Parsons (2009) found expressed enlargement of gizzard at 7 days of age, when the whole grains of wheat were included in the mixture for feeding one-day broiler. Enlargement is logical consequence of necessity for grinded feed, According to data from various studies, enlargement can be up to 100% (Svihus, 2011). Observed studies shown, when initiation of structural components of feed started, gizzard capacity was increased. This increase is more noticeable in relation to the increase size of the gizzard (Hetland et al., 2003).

An important dilemma is to be solved. Is it gizzard, which is poorly developed due to a lack of structural components in feed, or it is condition that can lead to weaker production characteristics of poultry. Wild ancestors of domestic poultry species, had in feeding large quantities of structural components, such as seeds or fibrous materials (Klasing, 2005). Summarizing, that the local poultry adapted to feed with a high content of structural components and therefore concluding necessity for normal development and function of gizzard (Svihus, 2011). Jones and Taylor (2001) showed that addition of integrated cereal nutrition, rarely lead to the appearance of zoomed proventriculus. Indications that for normal development of functional units, proventriculus / gizzard, presence of structural components in the meal is required (Svihus, 2011).

5.3 Particle size and its features

The experiment done by Nir et al. (1994) documented high gizzard development and lower pH in 7 day old chicken, reflecting in that chickens fed with medium or coarser particle size diets have greater influence, then those fed with fine particulate diets (A .M. Amerah et al., 2007). Gizzard can reduce the particle size of ingested feed and mix it with digestive enzymes (Duke, 1986). With possibility to fragment the particles it can apply mechanical pressure up to 585kg/cm2 (Cabrera, 1994). In such a particular case, it would end with negative effect on gizzard, especially on size and gut function (A .M. Amerah et al., 2007). Related to these matters, it is reflected to relatively underdeveloped gizzard (Taylor and Jones, 2004). Considering those circumstances, it can be presumed that gizzard is functioning more as transit than a grinding organ (Cummings, 1994). In the report of (Nir et al., 1995; Engberg et al., 2002) showed decrease of relative weight of gizzard and small intestine, when they were fed with pelleted rather than those fed with mash diet.

Gizzard weight and feed particle size are positively related, when composed diets are as mash diet. (Nir and Ptichi, 2001). Higher gut motility is obtained through large, well developed gizzard (Ferket, 2000), and also through increased level of cholecystokinin release (Svihus et al., 2004b). Therefore, on the other end reflects to higher secretion of pancreatic enzymes and the gastro-duodenal refluxes (Duke, 1992; Li and Owyang, 1993). Passage rate through gizzard may be affected and slowed down, when coarser particles are used (Nir et al., 1994). However, the exposure time of nutrients to digestive enzymes are increased to a certain level, which in turn, can improve nutrient digestibility and energy utilization (Carre, 2000). Gabriel et al., (2003) reports that pepsin activity is increased with lower pH of gizzard content, therefore it utilizes digestion of protein. With the appearance of low pH gizzard content, it has been reported that it may reduce the risk of feed-borne pathogens (Engberg et al., 2002) and coccidiosis (Cumming, 1994).

Feed particle size is recognized with multiple different properties, and one particular is relation between developments of digestive tract and feeding with mash diets (A .M. Amerah et al., 2007). The report by Nir et al. (1994) documented that lowering of intestinal pH and hypertrophy of the small intestine occurs also when fine mash diets are used in feeding process. Nir et al. (1995), found lower relative duodenal weights in birds fed with coarser particles. The importance of both, lower duodenal weight related with coarser feed particles is unclear and will certainly be part of deeper research (A .M. Amerah et al., 2007).

5.4 The optimal feed structure for poultry

The possibilities of modern types of poultry to break down structural components of feed are not tested to a greater extent. There are doubts, whether the goal is optimal structure of the mixture or the optimal share of coarser particles. Hetland et al. (2002) found that adding 30% of uncomminuted wheat lead to increased share of larger particles that enter the duodenum. Adding 44% of wheat grain resulted in a significant reduction in the share of small particles of 0.04 mm in the duodenum, but at the same time there has been a decrease in feed efficiency (Hetland et al. 2002). Smaller gains and poor utilization of nutrients were found in the appendix of 60% whole grain wheat (Hetland et al. 2002). Similar reduce in weight gain was obtained in the experiment of Biggs and Parsons (2009), when the proportion of whole grain in a mixture of wheat is increased from 35 to 50%. Related researches are not showing clear conclusions, but there is no upper limit of share of large particles in the mixture, in order not to disturb the growth rate and recoverable nutrients.

Svihus et al. (2004b) examined the influence of particle size in the mixture on the size of a gizzard in 10 different mixtures. Results are showing positive correlation between the content of particles larger than 1 mm and the development of gizzard, with the strongest correlation to the fraction of particles larger than 2.8 mm. Summarizing that particles larger than 1 mm, confirm an encourage growth of gizzard. The similar results were documented in the research of Nir et al. (1994), whose lead to increase of the gizzard for 26%.The difference between the control and experimental mixtures was particle size distribution with 25% more particles found in the group from 1.18 to 1.70mm. Related to his research, following recommendations should reach: at least 20% of particles larger than grains of 1.5 to 2.0 mm or at least 30% of particles larger than 1 mm (Svihus et al., 2004b). In a study conducted by Nir and Ptichi (2001) was found that increase of broiler growth lead to the increase in the optimum value of GSP-a mixture.

Another issue regarding the structure of feed, is the challenge whether should it be used in powder form or pelleted form. The general opinion is that pelleted feed increases the gain and lead to higher feed intake (Caleta, 1965; Choi et al., 1986; Nir et al., 1995). Genetic selection has led to the tremendous progress in gain of broilers. With pelleted feed, genetic potential is highly expressed. However, as a result of accelerated growth, there was a disturbance in metabolism, bone development and in cardiovascular system (Trevidy, 2005). On the other hand, it has been shown that the use of powder feed increases the weight of the digestive system of broilers (Choi et al., 1986) and the length of the small intestine, *jejunum* and *ileum* (Nir et al., 1994). Greater development of the gizzard is favorable, due to the presence of larger particles, which are mostly pulverized in pelleting process. However, there are many disadvantages of applying the powder mixture in breeding broilers such as weight manipulation mixture, layering, choice of particles by animals, dusting, loss micro components etc.. (Nir et al., 1994).

5.5 The effects of increasing the share of large particles in mixtures for poultry

It has been found that the particle size of the material in the small intestine of poultry is decreased, if in the longer period of time benefits the mixtures with a higher proportion of large particles. (Hetland et al., 2002, 2003; Amerah et al., 2009a). Related with previous facts, particle size in the small intestine is decreased but with a smaller proportion of large particles (Hetland et al., 2002, 2003; Amerah et al., 2009a). This is due to more developed gizzard and time efficient of grinded feed particles (Svihus, 2011). With the usage of electron microscope, Peron et.al. (2007) have noticed ingredients, such as eg. starch granules, that are trapped in a coarser particles in the thin intestine. However, when the gizzard is well developed, it will decrease the number of larger particles in the small intestine, leading to improved utilization of nutrients (Peron et.al. 2007).

Adding the structural components in the mixture for broilers reflects to a reduction in pH value of gizzard content of 0.2 to 1.2 pH units (Svihus, 2011). Therefore, explained by the higher volume of gizzard, and thus prolonged retention of feed, resulting in a greater amount of light and hydrochloric acid (Svihus, 2011). Since the pH value of feed ranges from 5.5 to 6.5, greater amounts, will reflect into increase in the pH value of the gizzard (Svihus, 2011). This is likely major reason for the higher pH values that gizzard is using from pelleted feed, compared with the powder, since the amount of incorporated pelleted feed is always higher (Engberg et al., 2002). The smaller share of large particles is due to pelleting, and grinding also contributes to this effect (Svihus et al. 2004b).

Lower pH value of content in gizzard contributes to improved digestion of feed, and in addition, also destruction of pathogenic microorganisms in nutrition (Svihus, 2011). In this way, the functionality of gizzard indirectly influence on animal health (Svihus, 2011). Bacteria of the genus *Salmonella* is one of the leading causes of alimentary toxically infections of people, and it is mostly associated with food products from poultry. The presence of larger particles over a longer period of time, reflects to increased development of broilers and gizzard, its larger volume and capacity (Huang et al., 2006). Thus, resulting in more feed reserves, and pathogenic microorganisms are destroyed due to the low pH values (Huang et al., 2006).

Similarly, different studies also point up, to reveal symptoms of coccidiosis broilers with increased share of large particles in feed (Jacobs, 2011). *Coccidiosis* is a disease which is caused by protozoa of the genus *Eimeria*, and it's a major problem in growing broilers (Williams, 1999). Followed by the reducing growth and weaker utilization of feed, causing a major economic loss (Braunius, 1987). *Coccidiosis* may be in the form of a slight infection, with almost no negative effect on the broiler, but they can also be manifested in the form of highly strong infections, causing high mortality (Williams, 1999). Increased incidence of this infection was, happened by introducing higher share of larger particles in the feed of broilers as a great potential. Assuming that it would avoid or greatly reduce the amount of applied coccidiostats, whose presence is prohibited in final products (Williams, 1999).

Gizzard as regulator of feed intake amount, play important role in prevention of overeating. Binge eating is characterized by normal weight gain, feed intake that is higher than the average, and the metabolic energy of less than 10.3 MJ / kg (Svihus, 2011). Overeating and poor utilization of feed ingredients, may result in poor development, due to small share of larger particles of the feed in gizzard (Svihus, 2011). Thus, the research of Peron et al. (2005) showed that broilers were fed with a small portion of larger particles, causing the pitiable development of the gizzard. After the poultry are left to starve for a while, they were given feed with apparent marks of overeating, whose lead in reduced digestibility of starch (Peron et al., 2005). In the study of Svihus et al. (2002), 4 out of 10 broilers were fed with finely-grinded wheat, with the signs of over eating. As a solution is force upon, that with addition of whole grains of wheat, broilers with symptoms of binge eating are eliminated.

Another positive effect from the presence of a greater proportion of larger particles is greater permeability of feed for the digestive juices in the stomach (Svihus, 2011). The feed in the stomach is made up from wide range of particle sizes, where in, the smaller particles fill the space between the larger ones. In this way, the finer particles reduce the permeability for digestive juices (Svihus, 2011). Increased content reflects in the appearance of larger particles and interspace, through where digestive juices pass, result with better digestion (Lentle et al., 2006).

5.6 Influence of particle size on the performance of poultry

Uniformity of particle size has the equal value as the size of feed particle in determining the influence of particle size on poultry performance (Amerah et al., 2007). Both can effect on poultry performance (Axe, 1995). By mechanoreceptors which are located in the beak, birds have possibility to distinguish the differences in feed particle size, which is highly important for their performance (Gentle, 1979). All researches can agreed upon one thing, illustrated in that poultry is recognized to have a preference for larger feed particles because of their digestive system (Schiffman, 1968). It was discovered at all ages (Portella et al., 1988) and thoughts were confirmed that particle size preference are related with increased age (Nir et al., 1994). It may be connected with the width of bird beak. With the increase of age, beak width is also increasing (Gentle, 1979), but there were no published data related to gape and its preferred particle size. For desired poultry performance, recommendations associated with particle size are, that particle size should increase with the increased age of bird. “Perfectly” uniform diet have significantly higher results on performance, gaining benefits from reduced spent time of searching for coarser particles. (Amerah et al., 2007). Despite the importance of discovery of Nir et al., (1994) where was used maize-soy diet in mash form, whose lead to higher weight gain and feed efficiency. Only limited studies have been done on how particle size uniformity of different cereal grains effect on poultry performance (Amerah et al., 2007). Due to the fact that greatest share of the feed used in the production of broilers is pelleted or grinded feed, there is a lack of interest because there is no opportunity for selection of the different particle size (Reece et al., 1986)

6 Effect of particle size on pellet quality and feed production economy

6.1 Definition of high quality pellets

Differences between high quality pellets and low pellet quality are in their ability to withstand mechanical handling (bagging, transport) without cracking (A .M. Amerah et al., 2007). Pellets of high quality will withstand all the obstacles on their way to feeder, while pellets of low quality will generate higher proportion of fines. (Svihus, 2009, HFE 305 course). There are two physical parameters for determining pellet quality, such as pellet durability index (PDI) and pellet hardness. The PDI is measuring the percentage of fines in mechanical handling (Behnke, 2001), typically in a tumbling can (ASAE, 1987) which imitates all standardized movements in the handling or Holman Pellet Tester (Miladinovic D. HFE 305 lab work). Determining of pellet hardness is done with small metal utensil, where it is measured static force (in kg) required to break the pellet. Measurements are done multiple times on different pellets and the average value is taken for final result. It is considered that pellet durability and feed efficiency have positive correlation (Carre et al., 2005).

As the pellet with higher durability withstand all wearing of mechanical handling, it nearly excludes the formation of fines, resulting in reduced feed wastage and also increased selection of larger particles for bird (Svihus, 2009, HFE 305 course). There are several factors affecting pellet durability such as dietary protein and oil contents (Briggs et al., 1999). However, we cannot exclude cooling and drying, and mash conditioning, as a highly important processes in the pellet durability evaluation. (Behnke, 1996). Cramer et al., (2003) has been reported that high starch gelatinization has positive effect on pellet durability. Thereby, it has been recognized that due to low starch gelatinization of coarser particles lead to appearance of poor pellet quality associated with coarser particles (Svihus et al., 2004a).

6.2 Importance of particle size on energy cost

Feed as one of the parts in the chain of costs in poultry production, contains the highest single cost (Amerah et al., 2007). Observing broiler industry, after pelleting process, reduction of feed particle size constitutes second highest energy cost (Reece et al., 1985). However, perceiving layer industry where pelleting process is excluded, grinding is regarded as the largest user of electricity (Deaton et al., 1989). Necessity to reduce feed particle size to a finer size requires higher energy use and hence lowers production rate, ending with negative reflection on production economy. (Dozier, 2002). Thus, if there are possibilities for any reduction in energy consumption in grinding process, all hesitation must be excluded, for targeted goal such as decreased feed cost. According to Reece et al. (1986) who reported that there are possibilities for major energy savings up to 30%, simply achieved by switching from smaller (4.76mm) to bigger (6.35mm) screen size of hammer mill. Thereby, the coherence between energy consumption and screen size in grinding process should not be considered as linear. “In multiple studies were shown that fineness in grinding process does not influence on the efficiency rate” (Martin, 1985), or on power consumption, both in pelleting process (Martin, 1985; Svihus et al., 2004a). Hence, considering productivity of birds, any gain from the reduction of particle size must be at least equal, or higher of the cost of fine grinding.

7 Valuation and calculations for poultry feed

7.1 Production costs of poultry feed

Behold poultry feed as a final product, it should be presented how many complex processes were necessary for the finalization of it. From unloading of materials in the storage until the packing as the last process in the feed mills, each of the processes takes places in the final cost calculation. On the top of the cost pyramid are the ingredients used in the production process (cereals, enzymes, additives), then power consumption and human labor, as some of the vital components in the creation of final calculation of costs.

The term of cost in the production generally refers for all the outlays in poultry feed production. As in every typical calculation, there is no difference in the calculation of poultry feed. Cost items are divided in two groups, fixed and variable cost summarizing with final cost of the feed. Particularly interesting study was done in Bangladesh where group of researchers have divided poultry feed production on high quality, medium quality, and low quality production. Comparisons were made and focus was on gross return (Haque et al., 2016).

Table 3. Production cost of different quality poultry feeds mills

Item	High quality (Tk./MT)	Medium quality (Tk./MT)	Low quality (Tk./MT)
A. Variable cost			
Raw Material cost	32203.9	32082	31389
Electricity cost	450.41	440	400.7
Marketing cost	3000	2888.3	2552.8
Maintenance cost	120.33	100.88	110
Interest on working capital	900.04	862.6	763
Total variable cost	36674	36373	35215
B. Fixed cost			
Land use cost	320.73	290	250
Machinery, Tools & Equipment cost	820.24	739.33	687.8
Building ,Warehouse& others cost	400.53	350.7	300
Salary & Wages cost	1030.1	850	730
Electrification gas/generator cost	20	10	10
Permanent labor cost	30	30	28
Total fixed cost	2621	2270.03	2005.8
Total cost(A+B)	39295	38643	37218

Profitability and forward linkage analysis of poultry feed mill in Bangladesh (Haque et al., 2016).

In table 3 production cost of high quality feed was higher than medium or low quality. If the observing point is on fixed and variable costs, it is noticeable that they are parallel decreasing with feed quality because the quality of feed mostly depends on the cost of different items (Haque et al., 2016)

If the gross return is considered as the targeted goal, than from table 3 it is possible to draw conclusions. From an angle of a customer, demand for higher feed quality is always one step above than for medium and low quality feed. Thus, production of higher feed quality looking upon the demands will be on the top of the scale even though the total costs are higher, but with higher price per unit for sale, it will compensate the difference and gross return will be higher. From all observed parameters, there is necessity to point up the advantage of high quality feed and following recommendations is the high quality feed in poultry production.

7.2 Power consumption in the production of poultry feed

As one of the highest input resources in manufacturing production, energy in most of the cases is on the top of the pyramid cost because it outweights other costs such as labors, maintenance and raw material which is not the case in poultry production (Fadare, 2003). Accordingly, it is one of the most important parameters and bases for development and economic uprising of observed country or region. Nowadays, with the growth of human population energy usage in agriculture has been intensified. Higher utilization of energy is reducing the risk of energy-related enviromental pollution, thus it also contributes to sustainable development (Kizilaslan, 2009; Ghorbani et al., 2010).

Grinding and pelleting are highly related to significant point-economical cost of production. The purpose of the production is to get as lowest price of cost per unit, to decrease the costs to minimum and that potential buyers get desired product in designed form for expected prize. Rewieving feed mill and all mechanical operations, total power usage around 80% comes from grinding and pelleting in the process of making feed. It means that gap for manipulation of cost and reducing usage of power consumption is not that flexible, but there is space for improvements.

There were some studies done in Egypt considering energy consumption for poultry feed (pelleted or mash feed). The determination of the energy consumption in manufacturing different type of feeds, poultry it was their aim and large animal feeds (Dabbour et al., 2014) This was achieved by determining the energy consumed in each stage of processing to assess the most consumable stage in the different types of feed. But the focus will be on poultry and pelleted or mash feed.

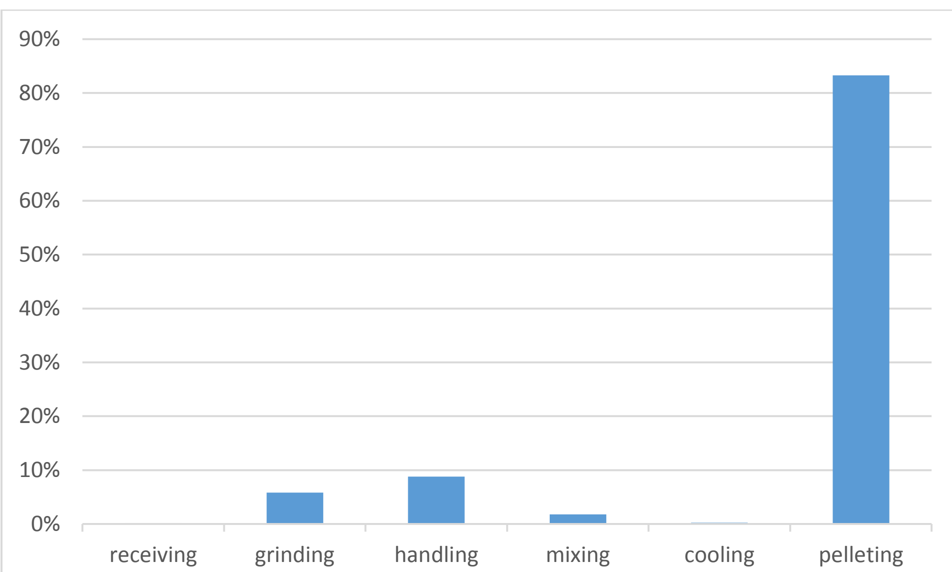

Figure 4. The percentage of energy consumption in manufacturing poultry feed pellets (Dabbour et al., 2014)

Figure 4 shows, as it ilustrated above, pelleting is taking part in most of the power consumption, concerning process of making pellets, the second one is grinding etc.

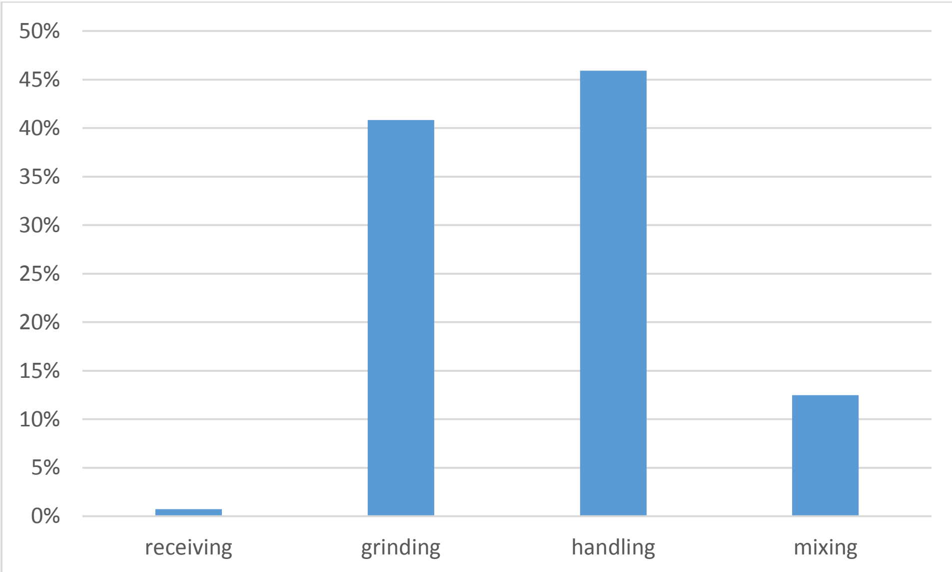

Figure 5. percentage of energy consumption in manufacturing mash feed for poultry (Dabbour et al., 2014).

Fig. 5, shows the percentage of energy consumption in manufacturing mash feed for poultry. On figure 5 it is obviously different situation than on the Fig. 4, now the grinding has taken the one of highest parts in energy consumption, and it can vary dependent of screen size in hammer mill.

Some of debate in the world of agriculture is also how to decrease power consumption in feed mills and certain operations. There are ways for sure, not known to everyone but different researches has been done, so one of the research was done in Norway in feed technology center in As called Fortek. Miladinovic and Salas (2014), did experiment how adding of different enzymes is affecting on power consumption in pelleting and grinding process and also on its pshycal quality. Main focus is on power consumption in pelleting and grinding process without adding any enzymes and water. It was consisted from 2 experiments, and first one was with ring die pelleting, and second one with different mixtures grinded in hammer mill with screen size 3 and 5mm.

Experiment 1

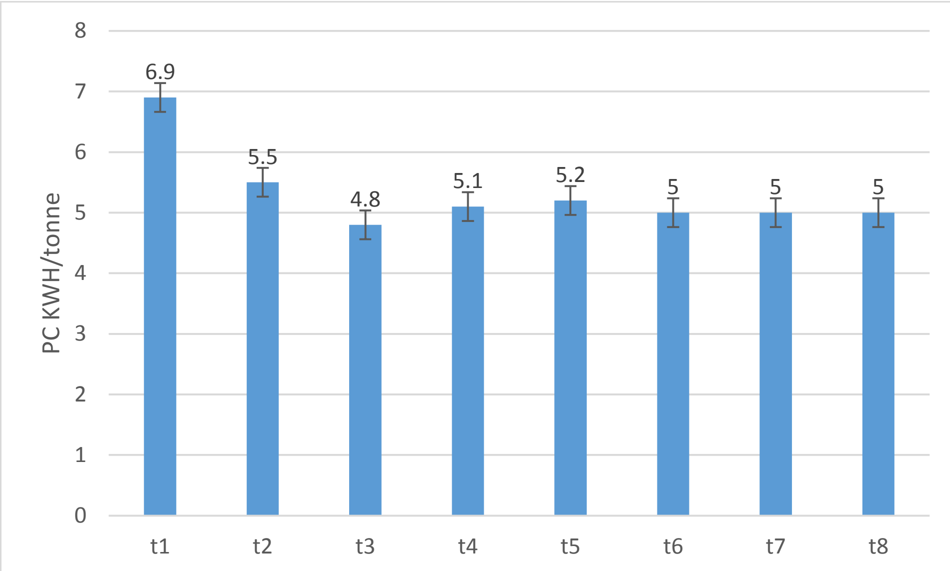

Figure 6. Power consumption (PC, mean±s.e.m.) during pelleting with or withouts enzymes (Miladinovic and Salas, 2014)

.

For this thesis research, treatment number (T1) is important because there was no addition of enzymes. It is clearly visible that power consumption (PC) has the highest level in T1 while in all other treatments PC has decreased, due to presence of enzymes. From PC view and aspiration on sustainable production and deacreasing the costs, it would be wise to use enzymes for pelleted feed.

The situation is same with grinding, other part of their experiment was to see how will 6 different mixtures react with or without adding water and enzymes and it was used hammer mill with screen of 3mm and 5mm.

Experiment 2

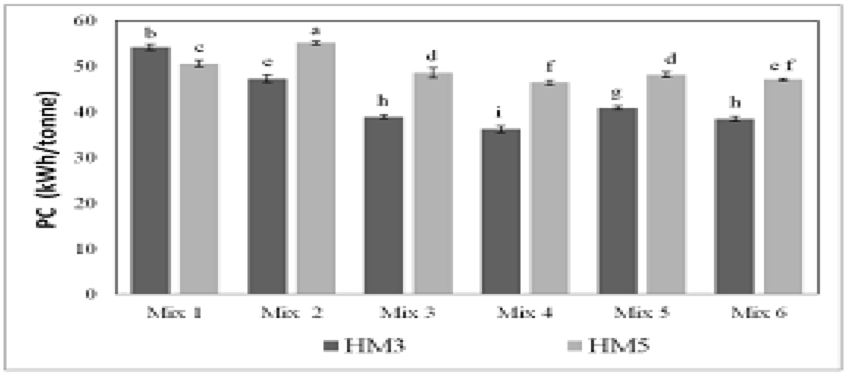

Figure 7. Power consumption (PC) for six different mixtures milled with 3 and 5 mm screen in a hammer mill (HM). Different letters indicate significant differences (Miladinovic and Salas 2014)

Clearly, mix 1 without adding any water and enzymes had higher PC in grinding of 100% barley on screen size 3mm, and obviously with 5mm lower. On the other hand, all other mixtures are showing that with adding of enzymes and water it is possible to deacrese PC which is important, independent of which screen size during grinding is used.

Independent of, for which animal specie feed is produced, pelleting and grinding are showing enormus PC usage in mentionted examples above. This still can be affected by different factors like adding enzymes, water and steam. It is known that poultry has preferences on bigger size particles, so by increasing the screen size we can decrease PC and definitely reduce costs, but solutions like adding enzymes and water should not be trown out of consideration.

8 Summary of mash and pelleted feed

8.1 Pelleted feed

The influence and effects of pelleting are well documented with known results such as: significantly improved growth and higher feed conversion ratio, easier ingestion, higher bacteriological quality, and in total in one pellet there is set of all necessary ingredients where there is no possibility for specific ingredient separation (Trevidy 2005).

Hardness and durability as the main physical indicators of pellet quality has influence on broiler reaction on the feed, but it is not ease to access it. In many different experiments where it was used pelleted feed as a point of research, for comparison pelleted feed gave greater result but also precise mash characteristics were not given (Trevidy 2005).

8.2 Mash feed

Quality of mash feed is dependent on the uniformity and size of its particles. As it is a form of complete feed which have all compounds of finely grinded and mixed feed, for birds it is not easy to easily separate out ingredients (Amakiri et al., 2013). Mash diets are not demanding complex manufacturing procedure, and with the simplicity of itself, have numerous positive advantages such as less death loss, it also gives greater consolidation of growth, and from economical aspect it is more profitable (Amakiri et al., 2013).

9 Discussion

9.1 Mash feed vs pelleted feed

Available data are suggesting that there are more critical points in mash feed then in pelleted. (Amakiri et al., 2013). Pelleting as a complex process is known with many attributes such as increased feed intake, and thus feed efficiency as well as improved weight gain (Nir et al., 1995; Jensen, 2000; Nir and Ptichi, 2001). These gains have been related to improved starch digestibility, higher density, increased nutrient intake and decreased energy spent for eating (Calet, 1965; Jensen, 2000).

In the past decade, there is a rising interest in feed particle size because industry is persistently searching the ways for feed utilization and for improvements in the field of production economy.

Advices and different recommendations within the optimum particle size, have been contradictory from the results of feeding trials. Trials were confounded by spectrum of different factors such as complexity of the diet, grain type, grinding method, and pellet quality and particle size distribution (Amerah et al., 2007). The volume of grinding have influence on various aspects of poultry production, adding development of digestive tract and bird performance (Amerah et al., 2007).

Last few year, with the appearance of many new feed mills, there is a rise in production of different forms of broiler feed for different age stages. In accordance with rising production, different types of feed forms have been evolved (Amerah et al., 2007). Pellet or mash as a form of feed, are the most significant components, which are reflecting on the total cost of feed, and on the end on the productivity performance of the broiler. The final goal of poultry feeding is process of conversion of the feed into human food (Amerah et al., 2007).

Mendes et al. (1995) in his study presented that birds which were fed with mash diets had a higher feed conversion efficiency than those fed with pelleted diet. Also death issues are important factor in intensive production of broilers, and it should not be ignored. Thus, Proudfoot and Hulan (1982) had observed the case of sudden death syndrome, and the results were in the favor of mash feed. There was significantly higher number of death for broilers fed with grinded feed. But also there are cases when the differences are small when it comes to comparing live weight gain between the birds fed with mash or pelleted feed (McAllister et al., 2000). “Pellet system feeding is a modification of the mash system” (Amerah et al., 2007). The process itself consists of usage of mechanical energy which is pressing the mash into pellets. Pellet gives a complete form of feed, which was compacted and extruded to about 1/8 inch in diameter and 1/4 inch long (Banerjee, 1998). One of the most significant attributes of pelleted feed and favorite in top management is that there is low percentage of feed waste, thus leftover can be used for other issues. After looking upon advantages, it is important to do deep analyses whether the disadvantage can be ignored. Pelleted feed is approximately 10% more expensive compared with others and the real challenge is to determine is the price difference big enough to cover the percentage of feed waste.

Asha et al. (1998) in his report got a conclusion that pellets had higher conversion rate for birds within the age of six weeks. Also, Moran (1990) in his report concluded that pelleted feed has positive impact on the body weight of poultry. Bolton and Blair (1977) reported that the difference in feed intake can go up to 10% into the favor of pelleted feed. Both forms of feed and method of feeding have positive and negative sides. The differences in both forms are reflected in digestibility, effectiveness, conversion efficiency and are noticeable different. There were some studies that has been undertaken to compare the productive potential of broiler birds fed with pellet/mash feed. One of the studies have been done by (Amakiri et al., 2013), and the experiment was about one hundred and twenty (120) Marshal day old broiler chicken that were observed in an experiment in order to compare the impact of pellet and mash feed on performance index. The chicken were randomly assigned to two treatmeants consisting of 60 birds/treatment with 20 bird/ replicate in a feeding trial that lasted for 6 weeks. Result from growth studies revealed that differences between pelleted and mash feed were not significant ($P>0.05$). However, results obtained revealed that mash diet significantly ($P<0.05$) improved feed intake. The results on cost benefit ratio showed that the cost/kg feed in mash feed is cheaper than the pellets. It was concluded that mash diet had beneficial effects (Amakiri et al., 2013). Apart from creating a source of variety for the birds, and for easy handling, mash feeding is more profitable in terms of weight gain and feed intake. Mash feed is also cheaper and easily available unlike the pelleted feed.

Observing cost analyses and profitability, there were different examples of studies where for instance from the case of production in Banglandesh, conclusion is that demands for high quality pellets are on the top of demand line. Considering that, expected level of quality must be high in intesive production of poultry feed (Haque et al., 2016). In the case from Norway, it is noticable that there is certain space for manipulation of power energy consumption. With expamples, such as incresing size of the screen in hammer mill, or adding enzymes (Miladinovic and Salas 2014). Enzymes are expensive, and there is necessity for cost benefit analysis, to have a view whether is it profitable or not, and certainly if the production appetite allows that. The situation in Egypt is illustrating that, observing process of making pellets, energy consumption is on the highest point. Meanwhile, observing the grinding process and proceding mash feed, level is acceptable (Dabbour et al., 2014). Concluding that appetite is on the mash feed side.

10 Conclusions

This thesis emphasizes the high importance of particle size of feed for poultry. The thesis reviews aninals' preferences to bigger or smaller particles, how the animals' mode of digestion is an important factor to determine optimal and cost-effective grinding. Every factor of production should be monitored, including the grains with high moisture level whose increasing energy consumption and significantly influence on grinding efficiency and thus feed price. Several studies have been to determine if mash feed or pelleted feed is optimal for poultry. Even though poultry prefer large particles, it's not possible to conclude that world wide production should go in one direction, because both mash and pelleted feed have positive and negative sides. However, pelleted feed seems to have more advantages then dissadvantages, and have given preferable results in experiments than mash feed. However, mash feed also provides a well balanced diet and birds can't easily separate out ingredients, also it gives greater unification of growth and it's more economical. In 3 different studies done by feed experts, there was similiraties in the results, even though the goal was different. Documented results are expressing recommendations for intensive production of high quality pellets, only in that direction cost effective analyses are presenting full scale of gains. However, still there will be doubt, and more researches and studies will be done in the future on this topic surely, at least with intention to reduce specificic energy consumption cost for making both types of feed, and definitely for better feed conversion ratio.

11 References

Abdollahi, M.R., Ravindran, V., Wester, T.J., Ravindran, G., Thomas, D.V., (2011). Influence of feed form and conditioning temperature on performance, apparent metabolizable energy and ileal digestibility of starch and nitrogen in broiler starters fed wheat-based diet. Animal Feed Science and Technology, 168, 88-99.

Abdollahi, M.R., Ravindran, V., Wester, T.J., Ravindran, G., Thomas, D.V., (2012). Effect of improved pellet quality from the addition of a pellet binder and/or moisture to a wheat-based diet conditioned at two different temperatures on performance, apparent metabolizable energy and ileal digestibility of starch and nitrogen in broilers. Animal Feed Science Technology. 175, 150–157.

Alles, G., (2003). Chapter II, about particle size reduction in Pet Food Technology. Available from Watt Publishing Co. US.

Axe, D.E., (1995**)**. Factors affecting uniformity of a mix. Animal Feed Science and Technology 53, 211-220.

Amakiri A.O, Owen O.J, Kpurugbara M.G (2013). Effects of mash versus pelleted feeding on broiler performance. Department of Animal Science, Rivers State University of Science & Technology, Port Harcourt. (3-5).

Amerah, A.M., V.Ravindran, R.G.Lentle and D.G. Thomas (2007). Feed particle size: Implications on the digestion and performance of poultry. Institute of food, nutrition, and human health, Massey University, Palmerston North, New Zeeland. World poultry science journal, Vol. 63.

Amerah, A.M., Ravindran, V., Lentle, R.G., Thomas, D.G., (2007). Influence of feed particle size and feed form on the performance, energy utilization, digestive tract development, and digesta parameters of broiler starters. Poultry Science, 86, 2615–2623.

Amerah, A.M., Ravindran, V., (2008). Influence of method of whole-wheat feeding on the performance, digestive tract development and carcass traits of broiler chickens. Animal Feed Science and Technology, 147, 326-339.

Amerah, A.M., Ravindran, V., Lentle, R.G., (2009a). Influence of wheat hardness and xylanase supplementation on the performance, energy utilization, digestive tract development and digesta parameters of broiler starters. Animal Production Science, 49, 71-78.

Amerah, A.M., Ravindran, V., Lentle, R.G., (2009b). Influence of insoluble fibre and whole wheat inclusion on the performance, digestive tract development and ileal microbiota profile of broiler chickens. British Poultry Science, 50, 366-375.

Anderson, S., (2007). Hammer Tip: Go High Speed to Control Particle Size. Feed Technology Update. 2, 18-21.

Angulo, E., Brufau, J., Esteve-Garcia, E., (1996). Effect of a sepiolite product on pellet durability in pig diets differing in particle size and in broiler starter and finisher diets. Animal Feed Science Technology, 63, 25-34.

Asha Rajini., Thanabalan. R.S., Narahari D. and Kumararaj R., (1998). Influence of season, form of feed and dietary energy levels on broiler performance. Journal of Poultry Science. 32, 36-41.

ASAE, **(**1987). Wafers, pellets, crumbles-definitions and methods for determining density, durability, and moisture content. American Society of Agricultural Engineers Standard S269.3. Yearbook of Standards, American Society of Agricultural Engineers, St. Joseph, MO.

Banerjee. G.C., (1998). Poultry Third edition. Oxford and IBH Publishing Co. Pvt. Ltd. Calcutta. 120-121.

Benhke, K.C., (1996). Feed manufacturing technology: current issues and challenges. Animal Feed Science Technology, 62, 49–57.

Benhke, K.C., (2001). Factors influencing pellet quality. Feed Technology 5, 19-22.

Biggs, P., Parsons, C.M., (2009). The effects of whole grains on nutrient digestibility's, growth performance, and cecal short-chain fatty acid concentrations in young chicks fed grinded corn-soybean meal diets. Poultry Science, 88, 1893-1905.

Bolton. W. and Blair R., (1977). Poultry Nutrition 4^{th} edition. Ministry of Agriculture: Fisheries and Food. Bulletin of Her Majesty Stationery Office, London. 174.

Briggs, J.L., Maier, D.E., Watkins, B.A. and Benhke, K.C., (1999). Effect of ingredients and processing parameters on pellet quality. Poultry Science 78, 1464-1471.

Cabrera, M.R., (1994). Effects of sorghum genotype and particle size on milling characteristics and performance of finishing pigs, broiler chicks, and laying hens. Master Thesis, Kansas State University.

Carre, B., (2000). Effects of feed particle size on digestive processes in birds breeding. INRA Production Animals 13, 131-136.

Carre, B., Muley, N., Gomez J., Ouryt, F.X., Laffitte, E., Guillou D., and Signoret C., (2005). Soft wheat instead of hard wheat in pelleted diets results in high starch digestibility in broiler chickens. British Poultry Science 46, 66-74.

Calet, C., (1965). The relative value of pellets versus mash and grain in poultry, World's Poultry Science Journal, 21, 23–52.

Calvacanti, W.B., (2004). The effect of ingredient composition on the physical quality of pelleted feeds: a mixture experimental approach, Ph.D. dissertation, Kansas State University, USA.

Gill, C., (2013). Article: Feeding the Hammer Mill, Feedstuffs. Watt publishing Co. Rockford.

Cumming, R. B., (1994). Opportunities for whole grain feeding. World Poultry Science. Association, Glasgow, United Kingdom. 9th European Poultry Conference, 2, 219-222.

Chaplin, S.B., Raven, J., Duke, G.E., (1992). The influence of the stomach on crop function and feeding behavior in domestic turkeys. Physiology and Behavior, 52, 261-266.

Choi, J.H., So B.S., Ryu K.S., Kang, S.L., (1986). Effects of pelleted or crumbled diets on the performance and the development of the digestive organs of broilers. Poultry Science, 65, 594–597.

Cramer, K.R., Wilson, K.J., Moritz, J.S., Beyer, R.S., (2003). Effect of sorghum-based diets subjected to various manufacturing procedures on broiler performance. Journal of Applied Poultry Research, 12, 404–410.

Dabbour, M., Bahnasawy, A., Ali S., and El- Haddad Z., (2014). Energy consumption in manufacturing of different types of feeds. Faculty of Agriculture Benha University Egypt. 1, 3-9.

Deaton, J.W., Lott, B.D. and Simmons, J.D., (1989) Hammer mill versus roller mill grinding of corn for commercial egg layers. Poultry Science 68, 1342-1344.

Dozier, W.A., (2002). Reducing utility cost in the feed mill. Watt Poultry USA 53, 40-44.

Duke, G.E., (1986) Alimentary canal: Anatomy, regulation of feeding and motility. In: Avian Physiology, (P.D. Sturkie, edition). New York: Springer Verlag, 17, 269-283.

Duke, G.E., (1992). Recent studies on regulation of gastric motility in turkeys. Poultry Science, 71, 1-8.

Đorđević, N., Dinić, B., (2011). Manufacture of the mixture of the concentrate feed. Krusevac, Serbia: Institute for forage plants.

Đorđević, N., Makević, M., Grubić, G., Jokic, Ž., (2009). Nutrition of domestic and farmed animals. Serbia, Zemun: Faculty of Agriculture.

Đuragić, O., Sredanović, S., Lević, J., (2002). Grit-essential characteristic quality of the feed, Journal of processing and energy in agriculture. 6, 44-45.

Engberg, R.M., Hedemann, M.S., Jensen, B.B., (2002).The influence of grinding and pelleting of feed onthe microbial composition and activity in the digestive tract of broiler chickens. British Poultry Science, 43, 569-579.

Ewing, W.R., (1951). Poultry Nutrition (4th edition). Pasadena, USA: The Ray Ewing Company.

Farner, D.S., (1960). Digestion and the digestive system, In Marshall, Academic Journal (Edition). Biology and comparative physiology of birds. New York: Academic Press. 54, 411-467.

Fadare, D. A., (2003). Development of an organic mineral fertilizer in processing plant. A Ph.D. thesis of Department of Mechanical Engineering, University of Ibadan. Ibadan, Nigeria.

Fahrenholz, A.C., (2012). Evaluating factors affecting pellet durability and energy consumption in a pilot feed mill and comparing methods for evaluating pellet durability. A Ph.D. thesis, Kansas State University, USA.

Ferrando, C., Vergara, P., Jimenez, P., Gonalons, E., (1987). Study of the rate of passage of food with chromium-mordanted pland cells in chickens (*Gallus gallus*). Quarterly Journal of Experimental Physiology, 72, 251-259.

Ferket, P., (2000). Feeding whole grains to poultry improves gut health. Feedstuffs USA September 04, 12-14.

Frølich, W., (1990). Chelating properties of dietary fibre and phytate. The role for mineral availability. In Furda, I., Brine, C.J. (Ed.) New developments in dietary fibre and phytate. New York: Plenum. 18, 83-93.

Friedrich, W., Robohm, K.F. (1982). Pre-wettability of components and mixtures, Part IV: Effect of different ingredients in mixtures and compression resistance. Force feed, 65, 92-102.

Gabriel, I., Mallet S., Leconte M., (2003). Differences in the digestive tract characteristics of broiler chickens fed on complete pelleted diet or on whole wheat added to pelleted protein concentrate. British Poultry Science 44, 283-290.

Gentle, M.J., (1979). Sensory control of feed intake. In: Feed Intake Regulation in Poultry, (Boorman K.N. and Freeman B.M., editors.). Edinburg: British Poultry Science Limited edition, 27, 259-273.

Ghorbani, R., Mondani F., Amirmoradi S., Feizi H., Khorramdel S. and Teimouri M., (2010). A case study of energy use and economic analysis of irrigated and dryland wheat production systems.
Applied Energy, 88, 283–288.

Heffner, L.E., Pfost, H.B., (1973). Gelatinization during pelleting. Feedstuffs 45, 32–33.

Hetland, H., Svihus, B., Olaisen, V., (2002). Effect of feeding whole cereals on performance, starch digestibility and duodenal particle size distribution in broiler chickens. British Poultry Science, 43, 416- 423.

Hetland, H., Svihus, B., Krogdahl, Å., (2003). Effects of oat hulls and wood shavings on digestion in broilers and layers fed diets based on whole or grinded wheat. British Poultry Science, 4, 275-282.

Heiman, M., (2005). Particle Size Reduction. In Schofield, E.K (Editor) Feed Manufacturing Technology, Chapter 8, Arlington, USA: American Feed Industry Association.

Jacobs, C.M., (2011). The effects of potential dietary prebiotics and grain particle size on the growth performance and intestinal microflora of young poultry. A Ph.D. Thesis, University of Illinois, Urbana, USA.

Jones, G.P.D., Taylor, R.D., (2001). The incorporation of whole grain into pelleted broiler chicken diets: production and physiological responses. British Poultry Science, 42, 477-483.

Jovanović, R., Dujić, D., Glamočić, D., (2000). Nutrition of domestic animals, Novi Sad, Serbia: Stylos-publishing.

Jensen, L.S., (2000). Influence of pelleting on the nutritional needs of poultry. Asian-Australian Journal of Animal Science, 13, 35–46.

Jones, F.T., Anderson, K.E., Ferket, P.R., (1995). Effect of extrusion on feed characteristics and broiler chicken performance. Journal Applied Poultry Research. 4, 300–309.

Kaliyan, N., Morey, R.V., (2008). Factors affecting strength and durability of densified biomass products, Biomass and Bioenergy, 33, 337-359.

Ka, S., Lindberg, J., Stromstedt, L., Fitzsimmons, C., Lindqvist, N., Lundeberg, J., Siegel, P.B., Andersson, L. and Hallbook, F., (2009). Extremely different Behaviors in High and Low Body Weight Lines of Chicken are Associated with Differential Expression of Genes Involved in Neuronal Plasticity. Journal of Neuroendocrinology, 21, 208-216.

Kenny M., (2007). The modern broiler requires optimal feed intake in order to support optimal and efficient growth. Aviagen, US.

Kersten, J., Rohde H. R., Nef, E., (2005). Principles of Mixed Feed production. Bergen/Dumme, Germany: Agrimedia.

Kizilaslan, H., (2009). Input–output energy analysis of cherries production in Tokat Province of Turkey. Applied Energy. 86, 13-54.

Koch, B.K., (1996). Hammer mills and roller mills. MF-2048 Feed Manufacturing. Department of Grain Science Industry. Kansas State University, Manhattan.

Koch, B.K., (2002). Hammer mills and roller mills. MF-2048 Feed Manufacturing, Kansas State University, Manhattan, USA.

Koch B.K., (2008). A PhD (Northern Crops Institute – North Dakota State University, USA).

Koster, H., (2003). Improved animal performance through feed processing technology. In Proceedings of AFMA annual symposium. 20-55.

Klasing, K.C., (1998). Comparative avian nutrition. New York: Oxford University Press.

Klasing, K.C., (2005). Poultry nutrition: A comparative approach, Journal of Applied Poultry Research, 14, 426-436.

Kvamme J.L and Phillips T.**D**, (2003). Preconditioning and extrusion. Pet Food Technology. Illinois. Watt Publishing Co.

Leclercq I., Horsmans Y., Desager J.P., Delzenne N., Geubel A.P., (1998). Reduction in hepatic cytochrome. Department of Gastroenterology, Catholic University of Louvain, Brussels, Belgium.

Lentle, R.G., Ravindran, V., Ravindran G., Thomas, D.V., (2006). Influence of feed particle size on the efficiency of broiler chickens fed wheat-based diets. The Journal of Poultry Science, 43,135-142.

LI, Y., and Owyang, C., (1993). Vagal afferent pathway mediates physiological action of Cholecystokinin on pancreatic enzyme secretion. Journal of Clinical Investigation 92, 418-424.

Lo, G.S., (1990). Physiological effect and physic-chemical properties of soy cotyledon fibre. In Furda,I., Brine, C.J. (Edition.), New developments in dietary fibre. New York: Plenum Press. 49-66.

Lund. D., (1984). Influence of time, temperature, moisture, ingredients, and processing conditions on starch gelatinization. CRC Critical Reviews in Feed Science and Nutrition, 20, 249-273.

Lucas G.M., (2004). Dental Functional Morphology. Cambridge University Press. Cambridge, United Kingdom.

M. A. Haque, M. Akteruzzaman, M. A. Hashem, S. Haque, (2016). Profitability and forward linkage analysis of poultry feed mill in Bangladesh. Department of Agricultural Economics and Department of Animal Science, Bangladesh Agricultural University. 14(2): 201– 208

Maier, D.E., Briggs, J., Watkins, B.A., (1999). Effects of ingredients and processing conditions on the pelleting of feeds. Completed research summary, Project 305. Tucker, USA: US Poultry and Egg Association.

Martin, S., (1985). Comparison of hammer mill and roller mill grinding and the effect of grain particle size on mixing and pelleting. Master Thesis, Kansas State University.

Mendes A.A, Polity E.S, Garcia E.A, Sartor J.R., (1995). Veterinary Animal Husbandry. 7, 31-40.

Miladinovic D. and Salas C., (2014). Influence of various enzymes and lignosulphonate on power consumption during pelleting process and physical quality of pelleted products. Annual transactions of the Nordic Rheology Society.

McAllister. A., McCracken K.J. and Magee F.A., (2000). Influence of grinding, rolling and pelleting on the nutritional value of grain sorghums and yellow corn for broilers. World Poultry Science Journal. 56, 215-222.

Moran, E.T., (1989). Effect of pellet quality on the performance of meat birds. In: Recent advances in Animal Nutrition. Butterworth, London.

Moran. E.T. Jr., (1990). Effect of pellet quality on the performance of meat birds. Poultry, Abstract, 16, 28-75.

Moore, S.J., (1999). Food breakdown in an avian herbivore; who needs teeth? Australian Journal of Zoology, 47, 625-632.

Nir, I., Melcion, J.P. and Picard, M., (1990). Effect of particle size of sorghum grains on feed intake and performance of young broilers. Poultry Science 69, 2177-2184.

Nir, I., Shefet, G. and Aaroni, Y., (1994). Effect of particle size on performance. 1. Corn. Poultry Science 73, 45-49.

Nir, I., Hillel, R., Ptichi, I. and Shefet, G., (1995). Effect of particle size on performance .3. Grinding and pelleting interactions. Poultry Science 74, 771-783.

Nir, I. and Ptichi, I., (2001). Feed particle size and hardness: Influence on performance, nutritional, behavioral and metabolic aspects. In: Proceedings of the 1st World Feed Conference, Utrecht, Netherlands, 157-186.

Ouchiyama, N., Tanaka, T., (1985). Kinetic analysis of the compaction process of a pellet in granulation. In C.E. Capes (Edition.), 4th International Symposium on Agglomeration in Toronto, Canada. 635-641.

Peron, A., Bastianelli, D., Oury, F.X., Gomez, J., Carré, B., (2005). Effects of feed deprivation and particle size of grinded wheat on digestibility of feed components in broilers fed on a pelleted diet. British Poultry Science. 46, 223–230.

Peron, A., Svihus, B., Gabriel, I., Bérot, S., Tanguy, D., Bouchet, B., Gomez, J., Carré, B., (2007). Effects of two wheat cultivars on physico-chemical properties of wheat flours and digesta from two broiler chicken lines (D+ and D–) differing in digestion capacity. British Poultry Science. 48, 370–380.

Portella, F.J., Caston, L.J. and Leeson, S., (1988). Apparent feed particle size preference by laying hens. Canadian Journal of Animal Science 68, 915-922.

Proudfoot. F.G: and Hulan H. W., (1982). Effect of reduced feeding time using all mash or crumble-pellet dietary regimes on chicken broiler performance, including the incidence of acute death syndrome. Poultry Science. 61, 750-754.

Reece. F.N., Lott B.D and Deaton J.N., (1985). The effect of feed form, grinding method, energy level, and gender on broiler performance in a moderate (21°C) temperature. Poultry Science. 64, 1834-1839.

Reece, F.N., Lott, B.D. and Deaton N, J.W, (1986). Effects of environmental temperature and corn particle size on response of broilers to pelleted feed. Poultry Science 65, 636-641.

Rodgers, N.J., Chost, M., Hetland, H., Sundby, F., Svihus, B. (2012). Extent and method of grinding of sorghum prior to inclusion in complete pelleted broiler chicken diets affects broiler gut development and performance. Animal Feed Science and Technology, 171, 60-67.

Rumpf, H., (1958). Principles and methods of granulation. Chemistry Engineering Technology, 30, 144- 158.

Ruetsche, P., (1989). Grinding/Sieving in the Feed Milling Industry. Advances in Feed Technology, No. 1, Detmold, Germany: Verlag Moritz Schafer.

Stark, C.R., (1994). Pellet Quality I. Pellet quality and its effects on swine performance. A PhD Thesis, Kansas State University, Manhattan, USA.

Skoch, E.R., Behnke, K.C., Deyoe, C.W., Binder, S.F. (1981). The effect of steam-conditioning rate on the pelleting process. Animal Feed Science and Technology. 6, 83-90.

Sredanović, S., Lević, J., Đuragić, O. (1997). Grinding in the feed mill, The Proceedings of the Symposium VII technology fodder "Improving the technology of production of animal feed". Tara, Serbia: Institute of Feed Technology, Faculty of Technology. 249-255.

Schiffman, H.R., (1968). Texture preference in the domestic chick. Journal of Comparative and Physiological Psychology 66, 540.

Svihus, B., Hetland, H., Choct, M., Sundby, F. (2002). Passage rate through the anterior digestive tract of broiler chickens fed on diets with grinded or whole wheat. British Poultry Science, 43, 662-668.

Svihus, B., Gullord, M., (2002). Effect of chemical content and physical characteristics on nutritional value of wheat, barley and oats for poultry. Animal Feed Science and Technology, 102, 71-92.

Svihus, B., Juvik, E., Hetland,H., Krogdahl,A. (2004a). Causes for improvement in nutritive value of broiler chicken diets with whole wheat instead of grinded wheat. British Poultry Science, 45, 1–6.

Svihus, B., Kløvstad, K.H., Perez, V., Zimonja, O., Sahlström, S., Schuller, R.B., Jeksrud, W.K., Prestløkken, E. (2004b). Physical and nutritional effects of pelleting of broiler chicken diets made from wheat grinded to different coarseness's by the use of roller mill and hammer mill. Animal Feed Science and Technology. 117, 281-293.

Svihus, B., (2009). Lecture notes Grinding, HFE 305 course, NMBU Department of Animal and Aquacultural Sciences.

Svihus, B., (2011). The gizzard: function, influence of diet structure and effects on nutrient availability. World's Poultry Science Journal, 67, 207-224.

Taylor, R.D., Jones G .P.D., (2004). The influence of whole grain inclusion in pelleted broiler diets on proventricular dilatation and ascites mortality. British Poultry Science, 45, 247-254.

Thomas, M., Van Zuilichem, D.J., Van der Poel, A.F.B., (1997). Physical quality of pelleted animal feed: 2. Contribution of processes and its conditions. Animal Feed Science and Technology, 64, 173–192.

Thomas, M., Van Vliet, T., Van der Poel, A.F.B., (1998). Physical quality of pelleted animal feed: 3 Contribution of feedstuff components. Animal Feed Science and Technology, 70, 59–78.

Van der Poel, A.F.B., Verstegen, M.W.A., Tamminga, S., (1994). Chemical, physical and nutritional effects of feed processing technology in: Process of the 16th Western Nutrition Conference. 19, 70–86.

Vilarino, M., Picard, M.J., Melcion, J.P., Faure, J.M., (1996). Behavioral adaptation of laying hens to dilution of diets under mash and pellet form. British Poultry Science, 37, 895–907.

Walter, M., (1990). The inclusion of liquids in compound feeds. In Advanced Feed Technology, Detmold, Germany: Verlag Moritz Schafer. 4, 36-48.

Wild, R. A., (1992). Hammer Mills and Roller Mills, Advances in Feed Technology. Detmold, Germany: Verlag Moritz Schafer. 8, 46-55.

Williams, R.B., (1999). A compartmentalised model for the estimation of the cost of coccidiosis to the world's chicken production industry. International Journal of Parasitology. 29, 1209-1229.

Wood, J. F., (1987). The functional properties of feed raw materials and the effect on the production and quality of feed pellets. Animal Feed Science and Technology, 18, 1-17.

Wootton, M., Bamunuarachchi, A., (1979). Application of differential scanning calorimetry to starch gelatinization, II. Effect of heating rate and moisture level. Starke, 31, 262.

Ziggers, D., (2001). Hammering or rolling the grain. Feed Technology. 5, 9-12.

Ziggers, D., (2010). Correct particle size benefits animal performance. All about feed. 3-8

Zimonja, O., Svihus, B., (2009). Effects of processing of wheat or oats starch on physical pellet quality and nutritional value for broilers. Animal Feed Science and Technology, 149, 287-297.

Web pages:

Trevidy,J.J.,(2005).Broiler feeding mash or pellet.

https://www.hubbardbreeders.com/media/broiler_feeding_mash_or_pelleten__083407300_1521_26062017.pdf

http://www.dummies.com/home-garden/hobby-farming/raising-chickens/the-digestive-system-of-a-chicken/

http://www.feedmachinery.com/glossary/equipment/roller_mills/

FAO, (2013). Aquaculture development and coordination program, fish feed technology. Chapter 18, Feed Milling processes.

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway