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WHAT KEEPS DRY PETFOOD TOGETHER? OPTIMIZING HOMOGENEITY, EXTRUSION MELT AND DEHYDRATION FOR BEST PHYSICAL QUALITY OF PETFOOD

Emmanuel Mensah Bentum
Master of Science in Feed Manufacturing Technology
Department of Animal and Aquaculture Sciences

WHAT KEEPS DRY PETFOOD TOGETHER? OPTIMIZING HOMOGENEITY, EXTRUSION MELT AND DEHYDRATION FOR BEST PHYSICAL QUALITY OF PETFOOD - A LITERATURE REVIEW

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Emmanuel Mensah BENTUM

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DEDICATION

Glory be to God for granting me wisdom, knowledge, understanding and making everything possible for me to accomplish my studies. I dedicate this work to my family, especially my parents, Mrs. Elizabeth Anokye, Mr. Frank Bentum, and my grandmother, Josephine Akua Birago, for their support in diverse ways in my education and to the success of this work.

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ABSTRACT

Extrusion is the most common method for producing dry pet food. This technology involves various operations such as mixing, heating, kneading, shearing, and shaping. Obtaining extremely homogenous mixes of the ingredients used in the extrusion process is a crucial factor. Improper mixing can decrease feed uniformity, which could affect animal performance and regulatory requirement. Feed producers must demonstrate the excellent quality of their materials by homogenous mixing of the components. Before the cooking process, the mixture homogeneity guarantees that the particle is thoroughly cooked. As a result, it gives the pet food better appearance and palatability. During the cooking process, nutrients undergo physical changes, with starch gelatinization being the most important for kibble binding and structure formation. The composition of raw materials, their quality, fineness of grinding raw materials, moisture content and processing conditions all affect the final quality of the pet food. These ingredients in the formulation may serve as a binding agent or fillers to help bind the feed together and improve palatability. Studies shows that extruded dry products normally do not need binders or additives just to increase the cohesiveness of the internal matrix, because the starches commonly included in the formulation are high enough in proportion to provide considerable structural enhancement. Gelatin, starches (corn, pea, tapioca, and potato) and many others are some of the binding agents utilized in the pet food industry. Some pet owners choose high-protein foods with lower quantities of starch, although starch helps the kibble form properly and not become crumbly. Lowering the starch content makes the extruded feed more prone to disintegrating. Gelatin, for example, has been suggested as a binding agent for high protein pet food, and may be able to compensate for the lost starch in pet food. To bind kibble together, commercial pet food manufacturers need a lot of carbohydrates (starch). It is difficult to shape and hold kibble together without starch, which is why most dry pet foods have a lot of it. Several research reported that starch aids in binding in the final product, particularly in dry pet food. Tuber starches such as potato and tapioca are excellent adhesive for improving final product cohesiveness. The main objective was to review extrusion technology currently used to process the pet food ingredients in order to obtain optimal physical quality.

Key words: Extrusion, gelatinization, protein, starch, gelatin, palatability, durability, hardness, water activity, moisture content, kibble.

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Abbreviations

BHT	Butylated hydroxytoluene
BHA	Butylated hydroxyanisole
NFE	Nitrogen free extract
STE	Specific thermal energy
SME	Specific mechanical energy
RS	Resistant starch
LIW	Loss in weight
SGD	Degree of starch gelatinization
L: D	Length to diameter ratio
µ	Microns
PDI	Pellet durability index
GMD	Geometric mean diameter
µm	Micrometer
%	Percentage
°C	Degree Celsius
mm	Millimeters
°F	Degrees Fahrenheit
AP	Amylopectin
AM	Amylose
aw	Water activity

1.0 INTRODUCTION

The pet food industry is rapidly expanding and has seen tremendous growth in recent years. Globally, the industry's key exporters of pet foods were France ($993 million), United States ($786 million), and Netherland ($511 million), and the major importers were Japan ($718 million), Germany ($617 million) and the UK ($563 million). In 2007, the global sales of dog and cat food reached US$ 45.12 billion, an increase of 4.9 % over the previous year (Dilrukshi *et al.*, 2009; www.petfoodindustry.com, 2009). In 2020, global pet food production increased by 8 % to 29.33 million metric tons, mostly due to increased demand in Europe (Philips Donaldson, 2021). The number of dogs worldwide is expected to be about 900 million and continue to increase, while the number of cats worldwide is about 600 million. According to Simplyinsurance.com (2021), around 470 million dogs and 370 million cats are kept as a pet globally.

Typically, a pet is fed only one type of the so-called "complete food" to meet all nutritional needs, including energy, protein, carbohydrates, fat, and micronutrients (Gibson and Sajid, 2013). The main goal of pet food is to provide consumers pet with a nutritionally adequate and acceptable diet, improve their longevity and prevent disease. Minimum and maximum nutritional guidelines for dogs and cats are published by the National Research Council (NRC) and the Association of American Feed Control Officials (AFFCO). (NRC, 2006; AFFCO 2007). The term "pet food" shall be used only to refer to dog food in this study. The hallmark of high-quality pet food is the guarantee that each pet receives all the needed nutrients required by the consumer. In several pet food production processes, obtaining extremely homogenous mixes of these ingredients is crucial. As such, manufacturers must demonstrate the excellent quality of their materials by homogenous mixing of all components (Herrman and Behnke, 1994).

Improper mixing can result in decreased feed uniformity, which could affect animal performance and regulatory requirement (Behnke, 1996). Feed mixes with numerous constituents have a variety of rheological characteristics. Due to this, there is a chance that mixtures will separate or disintegrate, which is usually as a result of segregation. Reduced feed ingredient homogeneity is thought to be caused primarily by segregation (Axe, 1995). As a result, poor mixing will adversely affect the quality of kibble (Axe, 1995).

To achieve high mixing homogeneity and provide a high-quality product, feed producers should concentrate on particle uniformity. This homogeneous mixture ensures that all nutrients are evenly distributed in the mixture, giving the animal a diet that meets its daily requirement for optimal performance and health (Axe, 1995). Homogenous kibble size and low levels of broken kibbles and fines are important traits that can be influenced by ingredients, type of starch level and processing conditions. As a feed manufacturer, it is important to ensure that the feed must be produced with the highest safety and quality standards (McCoy, 1994). The most prevalent type of pet food is the extruded dry food, which is very handy for owners (Harlow, 1997). This kind of product provides the crunch and chewing needed by the animals to maintain their general wellness (Crane *et al*., 2000; Carrión and Thompson, 2014). Cereal grains, meat, poultry/fish products, some milk products, vegetable fats/oils, vitamin and mineral supplements are all typical ingredients in dry pet diets. Several studies have shown the impacts of raw materials on the physical characteristics, palatability, and digestibility of extruded pet food (Felix *et al*., 2012).

According to Reimer (1992), factors such as feed formulation, particle size, conditioning, die specification, cooling and drying affect the physical quality of the feeds. Research has indicated that, some raw material mixtures do not bind together very well when processed. This would need the addition of special feed binders or binding agents such as gelatin, and others to improve the quality of the feed produced (Parr *et al*., 1988). However, the quantity and kind of starch and protein in the raw materials have a big impact on the feed quality. Its binding effect is affected by other factors, including moisture content, fiber content, oil content and the fineness of raw material grinding. These ingredients in the formulation may serve as a binding agent by keeping the feed together (Barszcz *et al*., 2014; Parr *et al*., 1988). Corsato-Alvarenga *et al*. (2021) reported that extruded kibbles, for example, often contain 30-60% starch components, which aid in kibble binding and expansion when cooked in the presence of water and heat. Extrusion processing gelatinizes the starch, making it more digestible in the small intestine. Heat treatment processing also gelatinizes substances that generally carry high bacterial (Kelley and Walker, 1999).

Knowledge on the fundamentals for aggregating particles of various sizes, hardness and shape is needed for optimizing product quality in terms of physical characterization. Hence, it is necessary to understand what holds dry pet food together, how particles bind, as well as how they behave during transportation and storage (Thomas and Van der Poel, 1996).

1.2 Aims of the study

The study seeks to:

i. to identify what keeps dry pet food together.
ii. to discuss extrusion technology currently used to process the pet food ingredients in order to obtain optimal physical quality.

CHAPTER 2. LITERATURE REVIEW

2.1 Pet Food Industry

The pet food industry is increasingly expanding, as pet owners demand high-quality diets for their animals. As a result of this requirement, manufacturers are looking for new ways to improve the quality of pet foods and/or the health of animals through a proper diet (Cipollini, 2008). Humanization or the treatment of animals as if they were humans, has become a worldwide trend in the last decade. Pets were first domesticated for the purpose of hunting or controlling rodent populations (Larson and Burger, 2013). As society grows more urbanized and atomized, pet companionship appears to meet a fundamental psychological need in many people (Larson and Burger, 2013). Currently, pet's owners treat their pets as part of the family, particularly dogs and cat providing companionship for their owners. Due to this, the gap between human and pet food is gradually closing, as pet owners want their pets to eat food that is similar to their own. This has urged the pet food sector to produce pet food products that are complete and nutritionally balanced. Complete and balance diets must satisfy both the nutritional needs and the expectations of their owners (Guazzelli Pezzali, 2019; Euromonitor International, 2016).

Pet owners demand high quality and spend more on their pet (Coriolis, 2014). A rising percentage of people are willing to pay a large premium for products that are "human grade," "grain free," "raw," "hypoallergenic," or have "superfood" components in the premium dog and cat food category (Euromonitor International, 2016). In the pet food sector, there has been a shift towards natural and healthy food. Pet owners frequently look for pet food claims that address the same health concerns they have within their own diet (Phillips-Donaldson, 2018). The grain-free claim has grown strongly in these trends. Pet owners believe that grains like corn and rice are not healthy for their pets, so the grain-free claim is a better option. Grain-free pet food sales grew 10% in 2007, accounting for 53% of new pet food products in the United States pet specialty (Phillips-Donaldson, 2018). Figure 1 shows the global pet food market size and growth.

Figure 1. Global pet food market size and growth.

Source;https://www.alliedmarketresearch.com/assets/sampleimages/pet-food-market1561111898.jpeg

The global pet food industry is characterized by pet type, food type, distribution channel, and geography (region). The sector is divided into three categories: dogs, cats and other pets. The dog food sector recorded the largest share of the global market in 2014. This is due to the increasing trend of nuclear families and consumers' growing preference for dogs for companionship, comfort and protection (Loomba, 2017). Dogs require a variety of nutrients to stay healthy. As a result, dog owners have focused on having proper food that contains these nutrients to keep their dogs safe. This is expected to boost pet food demand in the coming years (Loomba, 2017). Depending on the type of food, the global pet food market is categorized into dry pet food, wet/canned food, treats and snacks, and others. The market is divided into specialized pet stores, online sales, hypermarkets, and others based on the sales channel. The food market is divided based on region into North America, Europe, Asia-Pacific, and LAMEA (Latin America, Middle East, Africa). (Loomba, 2017).

Research studies shows that North America dominated the global pet food industry in 2020 which represented 38% of the total market. Western Europe**,** the second largest region, contributes for 22% of the global pet food market, while the Middle East is the smallest. (Globenewswire.com, 2021). Examples of the key players in the pet food market include Mars Petcare US Inc, Nestle Purina Petcare and, Diamond Pet Foods Inc (table 1) (Globenewswire.com, 2021).

Table 1. Top Global Pet Food Suppliers worldwide by their 2018 revenue (in million U.S. dollars)

Company	Home country	2018 Revenue	Year founded
Mars Petcare, Inc.	U.S.	18,085	1952
Nestle Purina Petcare	U.S.	13,200	1894
J.M. Smucker	U.S.	2,900	1897
Hill's Pet Nutrition	U.S.	2318	1948
Diamond Pet Foods	U.S.	1500	1970
Blue Buffalo	U.S.	1300	2003
Spectrum Brands	U.S.	821	1906
Unicharm Corp.	Japan	753	1961
Deuerer	Germany	721	1959
Heristo AG'S Saturn Petfood	Germany	700	1987

Source; https://www.thomasnet.com/articles/top-suppliers/top-suppliers-of-pet-food

It is known that the pet food industry faces significant challenges. Thus, consumer demands are influencing the industry to produce pet food products geared towards health and wellness, which may endanger pet food safety, and regulatory agencies are mounting pressure on pet food manufacturers to implement precautionary measures to protect consumer and pet health (Van de Ligt, 2019). To address this issue, teamwork is needed across the whole pet food supply chain to ensure that production techniques, food safety procedures all work together to preserve public health (Van de Ligt, 2019).

The approach to animal food safety is being altered radically by new laws and policies. Also, consumer needs, regulatory requirements, and the safety of pet food are all interconnected. The interplay between regulatory oversight, consumer expectations, and producers determines the success of the pet food sector (Fox and Kenagy, 2015). Pet food safety is becoming more of a concern for pet owners, as they have little ability to assess the safety of purchased pet food and have minimal recourse if their pets are hurt or killed by contaminated pet food. The safety of pet food is a concern not just for pets and their owners, but also for pet food manufacturers and distributors (Fox and Kenagy, 2015). In the United States several agencies and organizations govern the production, marketing, safety, and sale of commercial pet foods. Each agency has its own set of responsibilities and authority levels, which may or may not overlap. Table 2 shows the lists of the major agencies that regulate the production and sale of pet food in the United States, as well as their roles in pet food regulation (Case *et al*. 2010).

Table 2. Governing Agencies of Commercial Pet Foods

AGENCY	FUNCTION
Association of American Feed Control Officials (AFFCO)	Set nutrient standards for substantiations of claims. Provide model regulations for the states
National Research Council (NRC)	Collects and evaluates research and makes nutrient recommendations.
Food and Drug Administration (FDA)	Has the authority over approval of new ingredients Regulates health claims Ensures food safety
United States Department of Agriculture (USDA)	Regulates pet food labels and research facilities
Pet Food Institute (PFI)	Trade organization that represents pet food

	manufacturers
Federal Trade Commission (FTC)	Regulates trade and advertising

Source; (Case *et al*., 2010).

2.2 Dry pet Food.

Dry pet food is the most popular component of pet food market due to its ease of storage and feeding. Baked and extruded kibbles are examples of this sort of pet food (Case *et al*., 2010). Dry pet diets contain 6% - 10% moisture, as well as 90% or more dry matter. Dry pet food has a caloric density of 3000 to 4500 kilocalories (Kcal) of metabolizable energy (ME) per kilogram (kg). The dry matter (DM) percentage in dog diets varies depending on the purpose of the food, with fat content ranging from 8% to 22% and protein content ranging from 18% to 32% (table 3) (Case *et al*., 2010). Because of their low water content, dry pet foods are protected against spoilage, and antioxidants are added to prevent oxidative damage. The antioxidants can be natural sources such as vitamin E or synthetic in composition like butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) (Zicker, 2008).

Table 3. Nutrient content of dry dog food

	AF BASIS	DM BASIS
Moisture (%)	6-10	0
Fat (%)	7-20	8-22
Protein (%)	16-30	18-32
Carbohydrate (%)	41-70	46-74
ME(Kcal/kg)	2800- 4050	3000-4050

AF, As-fed; DM, dry matter, ME; metabolizable energy. **Source;** (Case *et al*., 2010).

Extrusion or baking is the most common methods for producing dry pet food. To produce extruded dog food, a number of ingredients are mixed to form a dough. After that, the material is further processed in a pre-conditioner with water and/ or steam. The material is then compressed and pushed through the die of the extruder (Rokey and Plattner, 1995). The mash is then cut into appropriate length or desired kibble size or type by rotating blades (figure 2) (Tran, 2008).

Then, the kibble is dried until it has reached a moisture content low enough to be shelf stable. It is simpler to coat kibble when the moisture content of the food is reduced to a minimum level. (Tran, 2008). The kibbles undergo a cooling phase. After cooling, the coating stage follows. The overall moisture content of the product (kibbles) is reduced to 10% or less using hot air drying (Ye *et al*., 2018).

Figure 2. Dry pet food (kibbles)

Source; https://www.gea.com/en/binaries/dry-petfood-kibbles_tcm11-65881.jpg

Extrusion, unlike baking, uses both mechanical and thermal energy, allowing for 90% to 100% gelatinization in extruded kibbles (Gibson and Sajid, 2013). The extrudate must have a specific amount of starch to be processed properly. Wheat is frequently used as an ingredient in baked products because the starch and gluten in wheat enhance the attractive texture and flavour of baked products. The cooking procedure improves the digestibility of the complex carbohydrates in extruded and baked dry meals, as well as their palatability (Case *et al*., 2010). According to Gibson (2015), extrusion lowers and kills bacteria in animal feed, but no research has shown that baking has the same impact. Koppel *et al*. (2014) reported that when researchers compared the sensory qualities of extruded and baked samples, they found that baked samples were lighter in colour and had lower levels of rancidity-related characteristics. When producing dry pet food, baking is less preferred than extrusion, however it was once popular. Baking is usually used to make treats, but it can also be used to make complete feeds. When baked kibble is prepared, the dough is spread onto large sheets and baked. The large sheets are split into bite-size pieces and packed when they have cooled (Case *et al*., 2010).

Baking allows for a greater variety of final product shapes than extrusion, which is one of the reasons it is utilized in treat manufacturing (Di Donfrancesco, 2016). Baked foods hold less air and have higher density than extruded kibbles (Dzanis, 2003; Beynen, 2000). One disadvantage of dry pet food is that they are less palatable than semi-moist or canned food for most dogs (Case *et al*., 2010). This is when the diets that are low in fat or contain substances that are difficult to digest or of poor quality (Case *et al*., 2010). Dry pet diets with high-quality materials and moderate to high fat levels, on the other hand, do not show reduced acceptance in dogs and are highly pleasant to majority of companion animals. Another disadvantage of dry foods is that they can only be made using dry materials. Also, the nutritional content and digestibility of some substances can be reduced by harsh drying (Girginov, 2007; Case *et al*., 2010). Companies that produced high quality, premium and super premium food used well treated materials and production procedures to ensure that their products digestibility stays high after processing (Case *et al*., 2010).

2.3 Extrusion Technology for dry pet food production

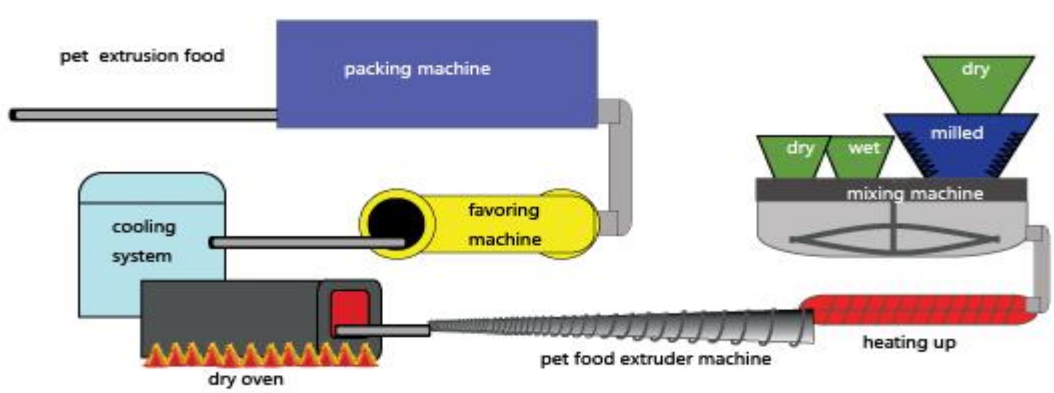

Figure 3. The working process of the pet food extrusion machine

Source;https://www.extrusion-machines.com/wp-content/uploads/2015/06/pet-food-extruder-production-line.jpg

2.3.1 Grinding

Grinding is a standard operation in the feed industry to reduce the particle size to produce ingredients suitable for animal feeding and digestion. The grinding method works by providing force to the ingredient to break the links between different physical structures in feed materials. Energy input and particle size reduction are key considerations in the dietary ingredient feed manufacturing process (Lyu *et al*., 2020). Reducing the size of the particles increases the surface area of the particles relative to their volume, thereby increasing the number of contact points between the particles (Muramatsu *et al*., 2015; Behnke, 2006). Prior to mixing, the particles are ground to provide a homogenous particle size distribution. This facilitates uniform moisture absorption by all particles. Before the cooking process, the mixture homogeneity guarantees that the particle is thoroughly cooked. As a result, it gives the pet food better appearance and palatability (Phillips, 1994; Tran, 2008). Also, other advantages of particle size reduction include easier handling and mixing of materials (Koch, 1996). Because fine grinding increases the specific surface area of particles, the material absorbs more water during conditioning. As a result of fine grinding, starch gelatinization increases, allowing for greater particle bonding in the feed. Fine grinding, in addition to reducing air space between particles and facilitating tight contact between particles in a processed feed, is required for good kibble quality (Koster, 2004).

In recent years, manufacturers have been more interested in the impact of feed particle size as they look for ways to improve feed utilization and production efficiency (Amerah *et al*., 2007). The most common equipment used to reduce the particle size of the feed ingredients are hammer and roller mills (Koch, 1996). Hammer mills are often used in the feed industry because of their great productivity and flexibility in grinding a wide variety of ingredients (Nwadinobi, 2017). The flexibility to work with any friable material or fiber is another advantage of the hammer mill. In addition, compared to roller mills, it has a lower initial purchase cost (Koch, 1996).

The hammer mill has a delivery device for putting material into the path of the hammers.

It has a rotor that consists of a series of machined disks mounted on the horizontal shaft (figure 4). The free-swinging hammers, which are suspended on rods, run parallel to the shaft and through the rotor disks (Koch, 1996). The hammers are rectangular metal plates, hardened or not that are bolted to the rotating shaft (Koch, 1996; Svihus, 2009). The screen is attached to the hammers from below, above, and/or around them (Nasir, 2005). To accomplish fine crushing and disintegration of input materials, hammer mills are operated at high speeds. The material being ground is first pounded by rotating hammers before being thrown against a perforated plate as it enters the grinding chamber (Nwadinobi, 2017). As a result of repetitive hammer strikes, collisions with the grinding chamber walls, and particle-on-particle impacts, the material is crushed or shattered (Svihus, 2009). Hammer mills often produced spherical particles with a polished surface (Koch, 1996). The hammer mill has the disadvantage of providing lower energy efficiency compared to the roller mill. In addition, it may generate heat, noise, and dust pollution (Koch, 1996).

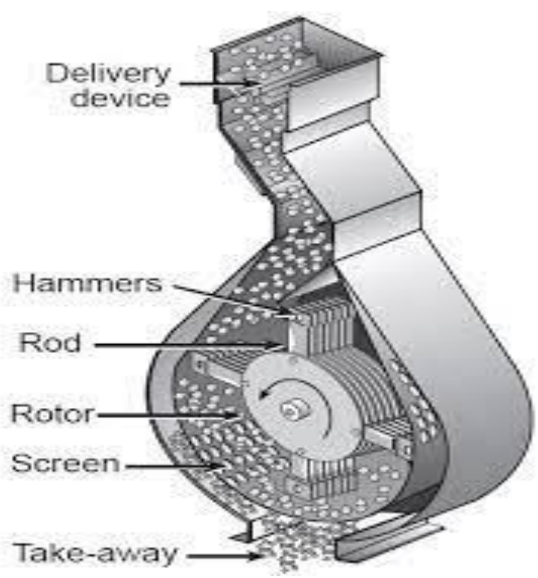

Figure 4. Hammer mill

Adapted from Koch, (1996)

Roller mills are not as widely used as hammer mills, still they should be regarded because of their benefits in terms of energy consumption, noise, lack of heat generation and thus moisture loss, and uniformity of particle size of the milled product (Koch, 1996; Svihus, 2009). A delivery device in a roller mill ensures that the material to be ground is delivered in a consistent and uniform amount (Koch, 1996). In a roller mill, the material is crushed as it travels between two or more pairs of counter-rotating rolls (figure 5). The speed of the two rolls can be the same or different. Shearing may be responsible for particle reduction when they travel at different speeds (Svihus, 2009). Each pair of rolls is placed so that one is stationary and the other can be pushed closer to or further away from it. The adjustable roll may be attached to a spring to protect the rolls if foreign hard material such as stones or metal fragments enters the mill (Svihus, 2009). By compressing the material between the rotating roll pairs, roller mills reduce particle size, resulting in a more uniform particle size distribution with a reduced proportion of fines. The resulting particles have an uneven, cubic, and rectangular shape (Koch, 1996). Roller mill grinding is best for brittle and friable materials (Svihus, 2009). The disadvantages of roller mills are that the investment cost can be a bit high, the design and use are relatively complicated, and its inability to grind fibrous materials (Koch, 1996; Svihus, 2009).

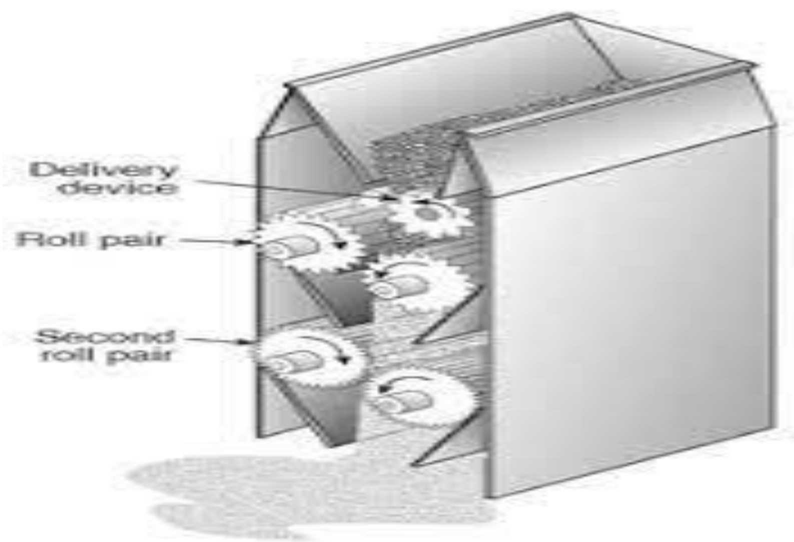

Figure 5. Roller mill

Source; (Koch, 1996)

2.3.2 Mixing

In the production process, mixing is regarded as the most crucial stage. It refers to the path that all ingredients must take to be blended into a supplement, premix, or complete feed in precise proportions (Fairchild and Moorehead, 2005). Mixing is carried out to ensure that all the ingredients are introduced in the correct quantities as specified by the formula (Muramatsu *et al*., 2015). To combine distinct macro and micro-elements into a homogeneous mixed mash, mixing is essential prior to extrusion. Proper mixing of the materials is necessary to generate a homogeneous mixture of proportionate materials (Martin, 2005). Poor animal performance might be caused by difficulties in supplying a homogeneous mixture of ingredients due to improper mixing (Behnke, 1996). According to Martin (2005), continuous and batch mixing systems can be used to mix feed ingredients, however most feed manufacturers favour batch systems. Batch systems measure and mix components in discrete batches according to a predetermined formula. The different types of mixers used in batch mixing systems include ribbon mixers, paddle mixers, and twin-shaft mixers. The material is then delivered to the preconditioner once it has been mixed (Martin, 2005).

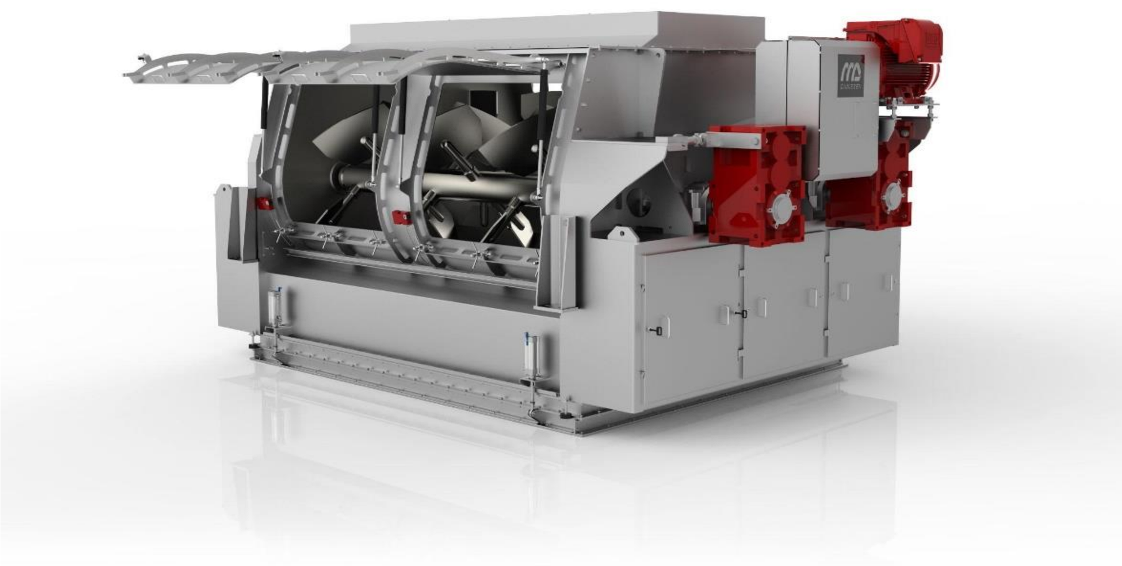

Figure 6. Feed mixer

Source;https://www.dinnissen.eu/uploads/images/c/5/c50798e5b3b8dab400deaf9deb0dd06d510d8f57/automatic/pg-4500-01-white.jpg

2.3.3 Conditioning process

Before the extruder, there is a chamber called a pre-conditioner. Since 1960, the preconditioner has been utilized in the pet food extrusion process as an important part of the extrusion system (Rokey *et al*., 2010). The preconditioner's main job is to pre-blend ground raw materials with steam, water, and other liquids, pre-heating and partially cooking the ingredients before they enter the extruder (Levine, 2014). The preconditioner is the main area for the application of specific thermal energy (STE), while it can also be added at the extruder barrel. Conditioning is required to ensure that the feed is of high physical quality (Muramatsu *et al*., 2015). Conditioning the mash with hot steam until extrusion has the aim of gelatinizing the starch in the feed and plasticizing of proteins (Smallman, 1996). Starting the starch gelatinization process, the preconditioner promotes internal hydration of food granules as well as plasticization and sanitization of the mass, improving extruder stability and product quality (Guy, 2001; Gibson and Sajid, 2013). These chemical changes result in viscous molecules that adhere to the less reactive components and hold the bulk together in terms of feed physical qualities (Smallman, 1996). Proper conditioning increases the quality of the kibble by introducing adhesive qualities to the surface of feed particles, resulting in a tougher kibble or fewer fines generated during further processing (Thomas and Van der Poel, 1996). After conditioning, the materials are transferred into an extruder, which performs the extrusion processes

2.3.4 Extruding (Extrusion cooking)

Extrusion is a shaping operation that involves forcing a dough-like material through a die (Riaz, 2000). Extrusion was initially used commercially to make pasta from wheat flour in the 1920s and 1930s (Jones *et al*., 1995). Extrusion cooking falls within the category of High-Temperature Short Time (HTST) processing (temperatures greater than 100°C) with pressure and shear applied (Moscicki and Van Zuilichem, 2011). Thermal and shear energies are applied to raw ingredients, resulting in structural, chemical, and nutritional transformations such as starch gelatinization, protein denaturation, flavour formation (Camire *et al*.,1990; Singh *et al*., 2007). These reactions alter the physical and chemical properties of the processed components, influencing the functional and nutritional qualities of the final product (Nolte, 2017).

In the extruder, the materials are cooked under pressure and exposed to a temperature of (80-200°C), which is high enough to efficiently achieve a food sterilization process that meets the industry requirement (Lankhorst *et al*., 2007; Zicker, 2008). The extruder is made up of a stationary barrel with a tightly fitting rotating screw inside, ending with a die. The rotating screw of the extruder pushes the mash through the die, which is then cut to the appropriate length or desired product type by rotating blades (Tran, 2008).

2.3.5 Drying, cooling, and vacuum coating.

Extrudates are often dried after extrusion to provide the necessary consistency and storage qualities (Tran, 2008). According to Rokey *et al*. (2010), several extruded products exit the extruder die with moisture levels above 18%, which requires the product to dry for storage stability. Sørensen (2003) reported that feed must be dried to a moisture content of less than 10% to prevent the growth of bacteria and molds. After drying, coating stage follows. Chaabani *et al*. (2020) stated that vacuum coating technology was successfully applied to pet food products where end-product quality and fat content are paramount. Studies conducted by Rokey *et al*. (2010) found that, to improve the acceptability and palatability of the products, several extruded dry foods used for companion animals add flavours or liquid fat after drying and cooling.

The coating cycle in extruded feed begins with sending dried kibbles to the vacuum coater at a chosen temperature of 70°C, sealing the mixing vessel, and creating a vacuum (Perez, 2001). At this point, the extruded kibbles are gently mixed in the coater chamber as the desired liquid is pumped in. After that, the vacuum is then released. The air is first taken out from inside of the kibbles, and then the vacuum is released. This allows the liquid to penetrate deep into the pores of the treated kibbles (Perez, 2001). After the drying and coating stages, the cooling phase is required to eliminate any remaining heat. Condensation can form in product storage bins or product packages if not enough heat is removed (Tedman, 2010).

2.4 Food components in extrusion formulation (effects of extrusion on starch, proteins, lipids)

All constituents in the extruded formulation are impacted differently by mechanical and thermal shear during extrusion, resulting in a variety of shapes (Guy, 2001). The effects of starch, proteins, and lipids on extrusion are discussed.

2.4.1 Starch

Starch is a key component of most dry pet food formulations, and it goes through several modifications throughout processing that affect the finished products digestibility, palatability, and physical qualities (Gibson and Sajid, 2013). It plays a major role in the nutritional value of the diet consumed by the companion animal. Companion animals tend to efficiently absorb starch because approximately 95% of dry pet foods are extruded, which gelatinizes the starch and improves its digestion (Spears and Fahey, 2004). The water stability, digestibility, and expansion ratio of extrudates are all influenced by starch gelatinization. The level of starch gelatinization, on the other hand, is dependent on the type of starch, particle size, and extrusion conditions (Rokey and Plattner, 2003). Gelatinization is also critical for kibble quality. The binding potential of starch in its natural state is lower than that of gelatinized starch (Kaliyan and Morey, 2009).

According to Wood (1987) diets produced with pre-gelatinized starch exhibited stronger kibble hardness and durability than those made with raw starch. Starch is composed of two glucans, amylose and amylopectin, which are arranged in granular forms in plant material (Huber and BeMiller, 2017). Amylopectin is more susceptible to shear during extrusion processing, according to Colonna *et al*. (1989). In superior plant starch, amylose and amylopectin can be organized in a semicrystalline structure to form a matrix of starch granules with alternating amorphous (amylose) and crystalline (amylopectin) material, which is known as the growth rings (Jenkins *et al*., 1993). After the starch granules are gelatinized, amylose immediately forms a double helix, which can aggregate (hydrogen bond) together and produce semi-crystalline regions (Moran, 1989; Schwartz and Zelinskie, 1978). Different grain starches have different gelatinization characteristics, reported by Lund (1984). Similarly, the degree of starch gelatinization varies depending on the technique of thermal processing (Lewis, 2014).

Cheftel (1986) observed that extrusion cooking causes granule swelling and breakage, as well as changes in crystalline spectra, increased cold water solubility, decreased starch viscosity, and the release of amylose and amylopectin. During extrusion the starch granules goes through several changes. They hydrate, swell, break down, and deteriorate, eventually transforming into a viscoelastic mass that expands as soon as it exits the die (Guy, 2001). Numerous studies have investigated the expansion ratio of starch during the extrusion process and its impact on extrudate physical qualities. In general, the higher the starch content, the greater the kibble expansion, however, the results are inconsistent in terms of extrudate expansion (Ye *et al*., 2018). The variations are attributable to changes in starch structure, properties of other raw materials, and interactions of starch with them, as well as inconsistencies in processing conditions (Ye *et al*., 2018). Temperature, moisture level before extrusion, amylose concentration, and lipid content are all factors that might cause structural changes in starch granules during extrusion (Tran, 2008).

Thomas *et al*. (1998) reported that because native starch lacks the functionality in terms of binding and adhesion to make durable kibbles, starch must be modified either during the feed manufacturing process or during a pre-processing phase to acquire feeds with excellent physical qualities such as hardness and durability.

2.4.2 Protein

Proteins go through a lot of structural changes during extrusion. They denature, hydrolyze, unfold, realign and react with other mash ingredients. The higher the protein content, the more intense the cross-linking between protein and carbohydrates, resulting in increased kibble rigidity (Onwulata *et al.*, 2001). The ideal protein sources are those that contain the essential amino acid profile required by animals (Willard, 2003). Protein inclusion in extruded foods is often lower than starch, favouring expansion, crispness, and bulk density (Day and Swanson, 2013). Research shows that heat treatment during extrusion cooking can damage the structural integrity of protein-based nutritionally active components, preventing them from fulfilling their roles (Van Der Poel *et al*., 1990; Alonso *et al*., 2000). Hendriks and Sritharan (2002) observed that mild denaturation of proteins can enhance their digestibility by increasing their susceptibility to digestive enzymes.

Wood (1987) studied the effect of raw versus denatured protein on pellet durability and hardness, finding that raw protein rations produced significantly stronger pellets than denatured protein diets. Proteins are frequently employed in the food and beverage sector because of their water-holding capacity, solubility, gelation, cohesive, and binding characteristics (Briggs *et al*., 1999). Thomas *et al*. (1998) reported that proteins are important in kibble binding because they exert sticky forces that aid in the binding of feed particles.

2.4.3 Lipids

Edible fat is used in pet food manufacturing as an energy supplement and a palatability enhancer. The addition of fat may be prone to oxidation during pet food production and storage, impairing the sensory and storage quality of the products (Lin *et al*., 1998). According to Rokey and Plattner (1995), during extrusion, hydrogenation, isomerization, polymerization, and lipid oxidation can diminish the nutrient content of lipids and various blends. Preservation of pet food is hindered by lipid oxidation. Many factors influence the rate of oxidation, including fat type, fat content, moisture content, and expansion degree, with unsaturated fats posing a greater preservation problem. Post-extrusion oxidation might potentially be impacted by the application of biological antioxidants (Lin et al., 1998). Lipids have lubricating properties and reduce friction between particles in the mix, as well as between the screw and barrel surfaces and the fluid melt, during extrusion processing (Guy, 2001). Lin *et al*. (1997) investigated the effect of lipids and processing parameters on the extent of starch gelatinization of extruded pet food and discovered that high lipid content in the extruding mixture could negatively affect starch gelatinization.

2.5 Types of extruders

2.5.1 Single screw extruder

A single screw extruder has only one screw in the barrel, which is commonly a fluted or grooved design. In a single-screw extruder, the screw is usually designed with a decreasing pitch to produce compression (Kowalski *et al*., 2017).

Feed, transition, and metering zones are generally seen on a single-screw extruder. While rotating in the barrel, the extrusion screws sequentially carry the incoming feed in the feed section and heat the feed to form a continuous plasticized mass (in the transition and metering sections) (Bhattacharya, 2017). Compared with twin screw, single screw extruder has advantages in cost, operation, and maintenance. Single screw extruders can produce pet foods with 17-20% fat content thanks to developments in preconditioning processes (Phillips, 1994).

2.5.2 Twin screw extruders

The twin-screw extruders are broadly classified based on the direction of rotation of the screws, either corotating (both screws rotating in the same direction) or the counter-rotating (screws rotating in the opposite direction). Further, they are categorized as intermeshing or non-intermeshing screws. For the intermeshing counter-rotating extruder, the screws jointly squeeze the product forward, while in the intermeshing corotating design, each screw wipes the other in moving the product forward (Guy, 2001). The pattern of the screw elements is designed based on the functions that are intended to be achieved by the screws. By proper setup of the screw elements, the operator can control the behaviour of material inside the extruder and influence the scope of physical and chemical processes in the extrusion cooking (Guy, 2001). Twin screw extruders have a wide flexibility in handling various ingredients and have higher productivity than single screw extruders. Twin screw extruders can operate in a wider range of moisture content, which is a disadvantage of single screw extruders.

Both single- and twin-screw extruders can benefit from preconditioning systems. The twin screw extruder has higher mixing efficiency, self-cleaning ability to prevent residue build-up**,** and relatively faster and more uniform heat transfer from the barrel to the ingredients (Ainsworth, 2011; Berk, 2009). With a twin-screw extruder, maintaining the consistency of high-fat products is simple. However, with twin-screw technology, fat levels can be up to 25% higher (Ferket, 1991). The twin-screw extruder is more often utilized in the food industry because of its wide range of operating conditions and capacity to manufacture a wide range of food products (Heldman and Hartel, 1997).

2.6 Factors affecting kibble quality.

Feed quality is a broad term that encompasses nutritional, physical, and sensory characteristics of feed. The physical quality is generally described as a processed feed's capacity to tolerate handling without generating excessive fines when extruded (Sørensen, 2015). The ability of a feed to match the nutritional requirements of the target animal is referred to as nutritional quality. Sensorial quality refers to the appearance, smell, and taste of the feed to the animal (Sørensen, 2015). Kibble quality is described as the ability to withstand fragmentation and abrasion during handling without breaking up, as well as the ability to reach feeders without generating a high proportion of fines (Amerah *et al*., 2007; Briggs *et al*., 1999). Commercial feed manufacturing companies and farmers emphasize the quality of kibbles. As production cost rises, profit margins are declining, so kibble feed producers must discover strategies to maintain good quality while cutting operating costs (Yasothai, 2018).

During storage, transport, and dispatch from the feed mill to the farms, kibbles are subjected to friction, impact, and pressure, and poor-quality kibbles break, resulting in a feed with a few kibbles and fines. (Mina-Boac *et al*., 2006; Lowe, 2005). The two main physical indicators of kibble quality are durability and hardness. Durability refers to the number of fines that return from kibbles after being exposed to mechanical agitation; hardness is the amount of force required to crush a kibble or series of kibbles at a time (Thomas, 1998). Studies show that kibbles should have a desired degree of hardness and be resistant to abrasion during handling, transportation and distribution to the animals (Thomas and Van der Poel, 1996). The amount and type of starch and protein in the raw materials have a big impact on kibble quality (durability and hardness). The moisture content, fiber content, oil content, and fineness of grinding of the raw materials all influence their binding effect (Barszcz *et al*., 2014; Parr *et al*., 1988).

These ingredients in the formulation may serve as a binding agent by keeping the feed together. According to Lim and Cuzon (1994), starch and protein improve kibble hardness and durability through chemical reaction by changing the nature of the feed mix in the presence of heat, moisture, and pressure. Fiber can be used as filler in the meal, lowering the porosity. As a result, the feed agglomerate's structural strength is improved, leading to increased kibble durability and hardness (Thomas *et al*., 1998). Reimer (1992) stated that the key factors controlling kibble quality are feed formulation, particle size, conditioning, die specification, as well as cooling and drying.

2.6.1 Feed or ingredient formulation

The least-cost formulation is created to suit the nutritional requirements of the target animal (Behnke, 2001). Least-cost diets allow nutritionists to save money on feed components by combining various ingredients to fulfill or exceed the nutritional requirements of targeted animal. The use of certain ingredients, especially by-product meals and alternate grain sources, may have an unintended impact on kibble quality (Buchanan *et al*., 2010). The inclusion of low-cost by-product meals such as dry distiller's grains with solubles (Koch, 2007) and oat hulls, for example, has been proven to reduce kibble quality (Buchanan and Moritz, 2009). More expensive feed ingredients, such as cellulose, soy protein isolate, and soybean meal, on the other hand, have been found to improve kibble quality (Buchanan and Moritz, 2009; Briggs *et al*., 1999). The addition of protein and fiber components improves the quality of the kibbles (Behnke, 2001).

Kibble quality is influenced by manufacturing methods in addition to diet formulation (Buchanan *et al*., 2010). The change in manufacturing technology will ultimately change the thermomechanical processing of feed ingredients (Buchanan, 2008). Different diet formulations, ingredient particle sizes, steam pressures, conditioning temperatures, and production rates may be used by each mill (Moritz, 2007). Higher conditioning temperatures have been proven to increase the quantity of moisture added to a mash diet (Turner, 1995; Cutlip *et al*., 2008), which is linked to improved kibble quality (Moritz *et al*., 2001; Hott *et al*., 2008).

2.6.2 Particle Size

Particle size has the least impact on kibble quality (Fahrenholz, 2012). Muramatsu *et al*. (2015) stated that reducing the size of the particles increases the surface area of the particles relative to their volume, which increases the number of contact points between the particles. Fine particles tend to absorb more moisture than larger particles, as a result, they require a higher degree of conditioning. Also, large particles act as fissure sites in kibble, causing cracks and fractures

(Kaliyan and Morey, 2009). However, intensive particle size reduction of feed ingredients may not be helpful to kibble quality (Muramatsu *et al*., 2015). Also, the large surface area of small particle sizes facilitates the transfer of heat and moisture to the mash inside the conditioner (Lowe, 2005). Turner (1995) stated that the recommended particle size for optimal kibble quality is 0.6 to 0.8mm. Frank and Rey (2006) suggested a particle size of 0.5mm to 0.7mm to produce durable kibbles. Even though fine particles make more durable kibbles, fine grinding is undesirable due to increasing production costs. Because the mixture of particles will make interparticle bonding with nearly no inter-particle spaces, a mixture of various particle sizes will give the best kibble quality (Grover and Mishra, 1996).

2.6.3 Moisture / water addition

Moisture has an important role in the extrusion cooking process (Riaz, 2000). Adding water to the preconditioner and extruder will increase the overall moisture content which is required for starch gelatinization and protein denaturation (Plattner, 2007; Riaz, 2007). When the feed contains insufficient moisture, the temperature and time required to cook it rises, necessitating the use of larger main drive motors (Strathman, 2007; Riaz, 2007). According to Riaz (2000), moisture in the form of steam is injected into the preconditioning device and the extruder barrel to provide additional energy for cooking. This enhances capacity while lowering the need for large drive motors. Moisture applied to a preconditioning device in the form of steam and water softens feed particles, lowering their abrasiveness. As a result, extruder component wear is reduced, lowering operating expenses (Riaz, 2000).

Moisture has a big impact on the end products quality (Onwulata *et al*., 1998). Riaz (2007) observed that extrusion at low moisture content produces a dense, unexpanded product. Kaliyan and Morey (2009) found that the strength and durability of densified materials increased as the moisture content increases until an optimum was achieved. Kibble particle binding is aided by both the water added to the mixer and the steam injected during conditioning (Muramatsu *et al.*, 2015). The amount of steam that can be introduced to the mash is assumed to be determined by the initial moisture of the mash entering the conditioner (Behnke, 2001). Riaz (2000) observed that vitamin losses and reduced amino acid availability are greatly accelerated as extrusion moistures are decreased.

2.6.4 Conditioning

Conditioning is one of the most important unit activities in the kibble manufacturing process. It is the process of transforming a mixed mash to a physical state that allows the feed mash to be compacted more easily using heat, water, pressure, and time in the manufacturing process. Conditioning improves the physical, nutritional, and hygienic quality of the feed produced while increasing production capacity (Skoch *et al*., 1981). To hydrate food particles and cook the starch and protein, moisture is required (Frame, 1994; Riaz, 2007). Moisture is a fluidizing agent that influences starch gelatinization and kibble expansion by regulating mass resistance to flow, viscosity development, and mechanical energy transference (Onwulata *et al*., 2001; Ding *et al*., 2005). Vukmirović *et al*. (2010) observed that the addition of water and steam during the conditioning process improves particle binding during feed processing, which has a positive effect on kibble durability.

According to Muramatsu *et al*. (2015), steam breaks down the structure of starch, causing it to gelatinize, and it also affects the tertiary structure of proteins. The combination of starch gelatinization and protein plasticization causes feed particles to stick together, which is vital to produce durable kibbles (Behnke, 1994). Kibbles with good durability, hardness, and hygienic quality, as well as improved nutritional value, can be made from well-conditioned feed mash (Thomas *et al*., 1997). Ungureanu *et al*. (2018) stated that, one of the most important parameters affecting the qualities of kibbles, such as bulk density or mechanical durability during storage and transportation, is the moisture content of the raw material. According to Plattner (2007), extrusion produces a dense, unexpanded product when the moisture content is low. The density of the product reduces as the moisture content increases, making the product lighter. However, as moisture content increase to a high level, the viscosity of the material in the extruder barrel decreases, making expansion of the product more difficult (Plattner, 2007). According to Ungureanu *et al*. (2018), kibbles are damaged during storage if there is more than 15% moisture.

2.6.5 Drying and cooling.

For safe storage, excess heat and moisture must be removed from the kibble (Kaliyan and Morey, 2009). The main goal of drying is to minimize the moisture content of an extruded cooked product. To prevent mold and bacteria growth, the final moisture content of dry extruded products must be less than 10% (Rokey *et al*., 2010). Moisture content gives useful information about product quality, but its only part of a complete moisture analysis. An important moisture measurement that determines the availability of water in a product is water activity (Carter and Fontana, 2008). In feed production, water activity has been used to determine if a feed is safe from microbial growth. It is widely used in the pet food industry and should be incorporated into all manufacturing processes and future regulation (Lowe and Kershaw, 1995). The most relevant information about product safety and quality comes from water activity. Water activity values are measured on a scale of 0 to 1(Carter and Fontana, 2008). Bacteria and molds both need water to grow, and every microorganism has a water activity threshold beyond which it will not grow. In order to avoid regulatory attention, feed must have a water activity of less than 0.85. Since there is not enough available water to allow bacterial growth at this value, a feed is considered non-hazardous. The water activity (aw) of dry pet food is between 0.40-0.45. With this low level of available water (<0.6 aw), microbial stability is not a problem (Timmons, 2006). After drying, the kibbles enter the cooling phase. Kibbles that have not been properly cooled may be less durable due to stresses in the kibble between the (cooled) outer layer and the (still) hot center, which causes cracks in the kibbles (Kaliyan and Morey, 2009).

3.0 Pet food palatability

Palatability is a very important property for pet food. Palatability is usually determined by how much is consumed in each food or on a daily basis or whether one diet is favored over another when different products are offered simultaneously (Watson, 2011). Case *et al*. (2010) stated that a dog would refuse unpalatable food regardless of the level or balance of nutrients it provides. Likewise, a diet can be palatable but still lack the necessary levels of certain nutrients. They must also be able to be absorbed by the animal’s body and stored in tissues and organs so that they can be utilized for essential activities. As a result, palatability, digestibility, and acceptability of pet food are critical characteristics, as a diet must be appealing to a pet to deliver optimal nutrition (Tobie *et al*., 2015). Bradshaw (2006) defined palatability as the perception derived at the time food is consumed and accounts for the flavor and the animal's perception of the appearance, taste, smell, size, texture and consistency and perhaps previous experiences. Acceptability and palatability are heavily influenced by the quality of ingredients and how they are cooked, processed, and stored.

Extrusion of grain starches, for example, gives dry pet food kibbles a desirable texture and flavor. Grain will be regarded as highly unacceptable if mold growth has developed or if the product has not been properly extruded. Food particles with high bulk densities are caused by poorly extruded starches, which have a negative impact on the texture and chewiness of the product (Case *et al*., 2010). A new product's development must not only be palatable, balanced, and nutritionally complete, but it must also be digestible. Typical protein, fat, and carbohydrate digestibility are 81%, 85%, and 79%, respectively, in commercial dry dog foods, while dry premium and super-premium pet foods can have a digestibility of up to 89%, 95%, and 88%, respectively, for crude protein, crude fat, and carbohydrate (Case *et al*., 2010). If the food is palatable, pet owners will find that their pet enjoys the food they gave, they will feel satisfied, and will be motivated to buy the food again. The combination of palatability and digestibility is therefore critical for a pet food's quality and consumer acceptance. However, often, palatability is the only important factor that determines a pet food's success or failure on the market (Aldrich and Koppel, 2015).

4.0 DISCUSSION

Forming kibble into a uniform and consistent shape is difficult without a binding agent. Manufacturers may use binders in their diets to achieve physical feed quality requirements like durability and hardness in pet food production. Feed binders are substance that are used to bind, glue, or hold the various feed ingredients together so that feed integrity is maintained (Baudon and Hancock, 2003). Feed integrity can be investigated by examining particle binding, which is attained by solid-solid linkages between diet ingredient particles or the application of particular feed binders, according to Thomas and Van der Poel (1996). Acar *et al*. (1991) found that binders can be used to minimize the amount of fines and enhance the feed integrity.

The mechanism of binding during feed processing, as reported by Tabil *et al*. (1997), is enabled by natural adhesion between particles and the mechanical load that forces inter-particle contact. The forces that bind various particles together are characterized as (i) solid bridges (they form at high temperatures and pressures as a result of chemical reactions, dissolved material crystallization, binder hardening, and melted substance solidification after cooling or drying), (ii) attraction forces between solid particles (hydrogen bridges, Van der Waal's forces, electrostatic, and magnetic forces between solid particles), (iii) mechanical interlocking bonds (during compression, particles and fibres, as well as bulky materials, can be folded and plied around each other), (iv) adhesion and cohesion forces between particles (produce from addition of viscous binders), (v) interfacial forces and capillary pressure (presence of liquids between particles, such as free moisture, produces cohesive forces between them) (Thomas and Van der Poel, 1996; Kaliyan and Morey, 2009).

Gelatin, starches (corn, pea, tapioca, and potato) and many others are some of the binders utilized in the pet food industry. According to Tabil *et al*. (1997), alterations in quality of ingredients such as increasing protein content or decreasing carbohydrate content can have adverse effect on the physical quality of kibbles; however, the authors affirmed that the use of feed binders can improve the quality. Binders function as both an adhesive and a filler, reducing void spaces and resulting in a more compact and durable kibble (DeSilva and Anderson, 1994).

4.1 Gelatin as a binding agent

Research has shown that, some pet owners choose high-protein foods with lower quantities of starch (Manbeck, 2016). However, lowering the starch content makes the extruded feed more prone to disintegrating, because starch is one of the key structure forming ingredients in extruded dry food (Manbeck *et al*., 2017). Dry pet food formulation with more protein has lower rates of expansion during the manufacturing process, which reduces kibble durability (Manbeck, 2016). This was affirmed by Zhu *et al*. (2010) who reported that, high levels of soy protein caused low levels of expansion due to starch-protein interactions where the proteins interfered with the continuous matrix of the product. The authors observed that, increasing protein concentration decreased void fraction. This can be resolved by the use of low-bloom gelatin in pet food in a palatable and cost-effective way (Manbeck, 2016).

Gelatin has recently been discovered in a growing range of new applications, including emulsifiers, foaming agents, and colloid stabilizers. Gelatin, according to Johnston-Banks (1990) is a soluble protein compound acquired by partial hydrolysis of collagen. It has the ability to swell and absorbs more water when it comes into contact with water (McWilliams, 2001; Mariod and Fadul, 2013). Afterwards, it can then be mixed with additional components and dispersed in boiling water. Sonac.biz (2021) reported that the rate of gelation increases as the concentration of gelatin increases, thereby increasing the gel strength. Advantages of the use of gelatin include improvement in stability during feed processing, maintenance of nutritional values of feed as well as improving digestibility (Sonac.biz, 2021).

Manbeck *et al*. (2017) observed that, the use of low-bloom gelatin increased feed expansion while maintaining the kibble's durability. As such, gelatin could be a viable option for addressing the durability and expansion difficulties that arise when making higher-protein pet food. Therefore, for protein fortification in pet food, gelatin is a better choice.

4.2 Starch; main binder in dry extruded food

Research has shown that starch has a significant impact on the physical qualities of many foods, and it is mostly used as a thickening, water binding agent, emulsion stabilizer, gelling agent and adhesive in the food industry. Starches derived from various plant sources have distinct qualities that enable them to withstand a wide range of processing techniques, as well as a wide range of distribution, storage, and final preparation conditions, using chemical or physical modification methods (Buléon *et al*., 1998; David and William, 1999; Daniel and Weaver, 2000; Singh *et al*., 2003)**.** Swelling power and solubility pattern, pasting behaviour, physicochemical, and functional properties of starch are all significant for improving the quality of food items (Shimelis *et al.*, 2006). Reports show that, most dry pet foods could have higher proportions of carbohydrate from 5% to 60% Rokey *et al*. (2010), and it undergoes numerous important modifications during processing that affect the final products digestibility, palatability, and physical characteristics (Gibson and Sajid, 2013) which is typically provided by cereals, pulses and tubers.

Cereals such as corn, sorghum, rice and wheat, pulses such as peas or lentils, and tubers such as potato or tapioca are the most prevalent starch sources in pet food. Grains, legumes, and tubers are useful ingredients for extrusion, in addition to being economical, available, and efficient sources of energy (Guy, 2001; Rokey, 2007). Studies shows that, carbohydrate holds kibbles together and gives it structure and texture and many other properties desired for specific final product in dry food (Petempire.us, 2020). For instance, in grained dog kibbles, a grain is used as a binder to keep the ingredients together. Again, when feeding a grain-free dog kibble, the binder is made of legumes, such as pea, chickpeas, or tubers, such as potatoes, or another starch (Onlynaturalpet.com, 2021). Most dogs are fed dry food, which is mostly made via extrusion. These require some structure-forming elements, like as starches, to aid in kibble expansion and increase food particle binding, texturization, and improvement in palatability (Guy, 2001).

Manbeck *et al*. (2017) affirmed that, extruded products normally do not need binders or additives just to increase the cohesiveness of the internal matrix, because the starches commonly included are high enough in proportion to provide considerable structural enhancement. In plant material, starch is made up of two glucans, amylose and amylopectin, which are organized in granular forms (Huber and BeMiller, 2017). Amylopectin is more susceptible to shear during extrusion processing (Colonna *et al*., 1989). Water-holding capacity, gelatinization, dough expansion, viscosity, and final density can all be affected by the total starch quantity and ratio of amylose and amylopectin. Maintaining a balanced ratio of amylose and amylopectin allows for maximum kibble expansion while minimizing fines (Tyler, 2021). According to Strathman (2007) the starch portions of the mixture have the maximum binding capability. Also, most of the formulations have enough starch to produce the desired kibble durability without giving much consideration to other natural binders like protein.

Riaz and Rokey (2011) stated that starch contributes significantly more to product binding and durability than denatured proteins and somewhat better than functioning proteins. The starch content in the final product depends on the nutritional requirements and the required bulk density (Rokey *et al*., 2010). The bulk density of extruded products can be reduced by increasing the starch content (Rokey *et al*., 2010). If a stronger, more durable product is needed, increasing the starch content will increase the adhesion to improve these properties (Riaz and Rokey, 2011). In most formulations, a minimum starch percentage of 40% is normal in dry expanded dog diets (Rokey, 2007). According to Rokey (2007), the source of the starch, as well as the type of starch, has a significant impact on how the starch behaves during extrusion. Tuber starches are more easily gelatinized during extrusion than cereal grains, which require higher temperatures and more severe processing. Because potato and tapioca starches have a high amylopectin-to-amylose ratio, they are commonly utilized as binding agents (Horstmann *et al*., 2017). When combined with water and heat, potato starch has larger oval granules than other starch sources resulting in high melt viscosity and early melting in the extruder (Della Valle *et al*., 1995). Table 4 summarizes the starch contents and gelatinization temperature of the principal carbohydrate sources.

Table 4. Starch contents and gelatinization temperatures for principal carbohydrate sources used in pet food

Carbohydrate source	**Starch (%, dry basis)**	**Gelatinization temperature (°C)**
Maize	73	70 – 75
Wheat	65	52 – 54
Barley	71	61 – 62
Sorghum	45	70 – 75
Rice	75	68 – 75

Source; (Riaz, 2007; Rokey, 2007; Allaboutfeed.net. 2018)

Literature on effect of cereals grain and their impact on the physical quality of extruded pet food are scarce. However, there have been some experiments about the use of various starches as feed binding agent in extruded aquafeed and pelleted feed. Due to the binding characteristics these starches possessed, it can be applied in extrusion of pet food, although few is known about its application in pet food industry. The ability of starch to swell, its solubility, the amount of amylose leached out during gelatinization, and hence the ability to make a viscous paste, all point to the significance of starch characteristics (Arisaka and Yoshii,1994). A study conducted by Tiamiyu and Solomon (2012) revealed that, starch sources derived from natural carbohydrates can be a possible alternative to synthetic binders in feed processing. Wheat starch was found to have the best binding properties and cause the least dustiness and was recommended as a good source of binder in feed processing (Tiamiyu and Solomon, 2012).

Mathew *et al*. (1999) observed that corn variety significantly affected expansion, breaking strength, and bulk density of a pet food in a study testing three distinct corn samples with similar grinding and extrusion parameters. As a result, pet food processing may be influenced by maize variety, growing conditions, the amylose-amylopectin ratio, and the levels of each ingredient (Corsato Alvarenga *et al*., 2021). Tiamiyu and Solomon (2012) found that among the cereals grain (millet starch, guinea corn starch, wheat starch, maize starch, rice starch) tested, rice starch produced the highest feed quality in terms of hardness.

There is a scarcity of scientific documentations on the use of legumes and tubers in pet food extrusion. Tuber starches with high amylase content, such as potato and tapioca, are also excellent adhesives for improving final product cohesiveness (Rokey *et al*., 2010). Studies shows that potato starch produces high viscous flow during the cooking process and demonstrated outstanding swelling and binding capacity (Guy, 2012, Hui, 2006; Riaz, 2006).

Potato starch may contain amylose (20-25%), which could be added to extruded product to provide further expansion and improved functional qualities (Guy, 2012). Studies shows that tapioca starch also has a very high viscosity, good binding properties and only moderate temperature is required during extrusion cooking (Riaz, 2006; Hui, 2006). In comparison to cereal grains and tubers, legumes are not considered to be as substantial a structure forming component. However, legumes such as (pea, chickpea, beans, and lentil) are highly useful components in extrusion. They have outstanding water absorption and binding properties (Guazzelli Pezzali, 2019). Corsato-Alvarenga and Aldrich (2019) evaluated the influence of dehulled faba beans (DFB) on the extrusion of dry dog food. According to the authors, drying caused kibble shrinkage, which resulted in harder and tougher kibbles as DFB increased.

4.3 Optimizing pet food safety and quality control

Companion animals play a vital role in people's lives, including their owners' emotional and physical well-being, who now regards their pets as "family members" (Headey *et al*., 2002; Di Cerbo *et al*., 2017). According to Buchanan *et al*. (2011), most pet owners take the responsibilities for their pets' health and well-being very seriously. As a result, a proper diet is required to successfully meet pets' needs, guaranteeing their long-term health and well-being (Daumas *et al*., 2014; Rolinec *et al*., 2016). Buchanan *et al*. (2011) stated that pet owners are heavily focusing on high-quality, commercially produced pet foods to provide convenience and proper nutrition throughout an animal's life. The quality of extruded pet food is critical, and maintaining that quality is essential. Manufacturers must guarantee that their products are nutritious and palatable to be acceptable and match customer expectations (Rokey *et al.*, 2010).

According to World Health Organization (2003), the quality of a product includes all other attributes that affect the value of a product to consumers. This comprises negative characteristics like spoilage, dirt contamination, discoloration, off-odors, and good aspects like the food's origin, color, flavor, texture, and processing method. Feed safety and quality control begin with selecting the highest quality raw materials from reliable suppliers (Hari.ca, 2021). The choice of ingredients significantly impacts the texture, uniformity, extrudability, nutritional quality, and economic viability of the final product (Riaz, 2000). Rokey *et al*. (2010) stated that the significance of choosing high-quality raw materials cannot be emphasized. When quality ingredients are formulated in a nutritious, well-balanced diet, proper processing is required to maintain their quality. Buff *et al.* (2014) reported that feed processing could significantly impact nutritional value, depending on the technology used and desired output. Tran (2008) stated that extrusion will change the metabolic rate of carbohydrates, vitamins, proteins, lipids and will affect nutritional qualities of extruded products. Bjorck and Asp (1983) stated that denaturation of proteins and changes in carbohydrate structure can affect the nutritional qualities of extrudates.

Studies show that unwanted enzymes are denatured during the extrusion process, anti-nutritional factors are destroyed, and feed is sterilized, all of which do not compromise the natural smell and taste (Riaz, 2000; Altan *et al*., 2009). Extrusion considerably increases the digestibility of starch, according to Dust *et al*. (2004). Bertrand *et al*. (2019) reported that the extent to which a starch can be gelatinized is determined by its water content, heating temperature, and cooking time. Lankhorst *et al*. (2007) stated that in a canine diet, the degree of starch gelatinization increased with increasing extrusion temperatures up to 150°C. Studies shows that due to the lack of sufficient water to swell starch granules and access their internal structures for solubilization, starch gelatinization is more difficult to achieve in limited or low water conditions (where starch is in excess). This means that gelatinization should be done in high water conditions from a process perspective (Wang and Copeland, 2013; Fukuoka *et al*., 2002). According to Tran *et al*. (2008), when measuring the quality of dry food, the gelatinization of starch and the shape of the final product is considered. Research has shown that the processing method impacts nutritional value by influencing the moisture content of the final product (Buff *et al*., 2014).

Rokey *et al*. (2010) discovered that monitoring the final product moisture content is critical for ensuring stability during storage. Dry extruded food has a maximum moisture level of 12%. (Rokey *et al.*, 2010). Case *et al.* (2010) found that dry pet food has a longer shelf life since they contain less moisture. According to Timmons (2006), an essential aspect of feed quality is the stability of the final product, and water activity (aw) is one of the critical characteristics that influences feed stability. Beuchat (1983) reported that microorganisms have a water activity threshold below which they can't grow. Controlling microbial development in pet food is a top priority since microbial growth poses health and safety issues (Deffenbaugh, 2007). Carter and Fontana (2008) discovered that water activity, not moisture content, determines the lower limit of water available for microbial growth. Lowe and Kershaw (1995) reported that manufacturers must find measures to ensure product quality and safety in order to maintain customer confidence. Product recalls are frequently caused by microbial deterioration. Katz and Labuza (1981) reported that water activity is also an indicator of pet food's physical characteristics and stability. Water activity has long been utilized in the food industry as a reliable indicator of microbial growth safety. Water activity should be an essential part of the manufacturing process and any future regulations (Lowe and Kershaw, 1995).

According to Başer and Yalcin (2017), the aw range for dry pet food and hard treats is commonly 0.40-0.45. Microbial stability is not an issue at this low level of available water (<0.6 aw). Research studies have shown that drying enhances product stability and shelf life, improves handling, and reduces product weight for shipment. Moisture can accelerate microbial growth, leading to spoilage or toxin production if extrudates are not dried or stored properly (Tran, 2008). According to Carter and Fontana (2008), because bacteria, yeast, and molds all require a certain amount of water to develop, drying pet food below a threshold aw level is an excellent way to keep microbial growth under control. The feed's structure, texture, and stability are all maintained by controlling water activity. According to Carter and Fontana (2008), water activity is a quick, low-cost, and precise approach to ensure that pet food is of good quality and safe. Any manufacturing plant or quality control laboratory can readily implement it. As a result, water activity is a valuable tool for keeping pet food stable, high in quality, and safe. Hence, it is important for manufacturers to ensure that feed must be produced with the highest safety and quality standards (McCoy, 1994).

5.0 CONCLUSION

Pet food physical quality is very important especially during transport and storage aside meeting regulatory and consumer demands. This review explored factors that keep dry pet food together during the extrusion process in order to get the best physical quality of pet food. The feed composition, processing techniques and post extrusion processes and other several factors affect the feed physical quality in varying degrees. Feed binders render feed compact and strong as well as acts as an adhesive and a filler. Alternatively, kibble binding is aided by gelatinization of the starch component of the feed giving it structure and texture. Again, the amount and source of carbohydrate and protein component in pet food and the degree of cooking influences its physical quality with pre-processed proteins playing very little role in feed binding. Other factors such as moisture content and water activity aids in the physical quality of pet food.

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

Postboks 5003
NO-1432 Ås
Norway