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Development of a Pelletizing System of Fermented TMR for Pig Feeding

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Abstract

Purpose: Fermented feedstuffs have been found to improve productivity, reduce manure odor, and increase immunity. However, because there is not a commercialized pelletizing system for fermented total mixed ration (TMR) for pig feeding in Korea, a pelletizing system using TMR fermented feed was developed. **Methods:** The particle size, density, and volumetric density of the TMR feeds used in the test were measured. The pellet durability index (PDI, %) value of the pelletized TMR feed based on its moisture content, and the amount of pellet production based on the rotation speed of the compression roller were measured. **Results:** The test materials, TMR1 and TMR2, were approximately compressed to 387 kg/m3 with 18.2% (w.b.) and 544 kg/m3 with 22.2% (w.b.), respectively. Throughout this pellet molding test, the moisture content from 15 to 20% (w.b.) of mixture feedstuffs, including fermented forage, could be used for pellet molding. Based on the results, a small-scale pellet molding system of fermented TMR was designed and manufactured for pig farms. As rotation speed increased, the throughput increased, whereas the moisture content decreased by approximately 2% (w.b.) because of pellet molding. The best yield of pellets with 94.2% PDI was of 536 kg/h at 135 rpm rotation speed. **Conclusions:** Although the throughput of the prototype increased as the rotation speed increased, it was difficult to operate because of the greater noise and the lower PDI (%) at the higher rotation speed of the pellet molding rotor. It was found that the best production of pellets using the prototype was 536 kg/h having a PDI of 94.2% or more at a rotation speed of 135 rpm.

Keywords: feed, molding, pellet, pig feeding

Introduction

The price of imported corn increased from $157.47/ton to $305.87/ton in 2012 (Hong, 2012). Because of the increase in price and the deterioration of the external environment, such as the Korea-Europe and Korea-America FTAs, it is urgent to improve the productivity of livestock farmers and reduce feed costs. The major part of livestock management is feed costs. Milk and cow farms have been supplying TMR (total mixed ration) completely using various feed sources in addition to compound feeds. In particular, in Japan, where the situation is similar to that in the Rep. Korea, the government promoted the echo feed project based on the Basic Plan for Food and Agriculture Rural Development and the Food Recycling Act (enacted in 2001), with food company by-products, and the rest from large restaurants for resource recycling (MAFF, 2012). In the field of swine farming, TMR feedstuffs using by-product have been actively studied, and feedstuff production techniques to raise high-quality pigs using local agricultural by-products have been reported (Shimazawa, 2009). The use of liquefied feedstock or high-yield corn by-products is becoming common practice for growing pigs in Europe (Gatel et al., 1988). The pellet production system has been used widely in Europe and the United State because the pellet molding of feeds has many advantages, such as the ease of feed storage and transport and improved feed productivity (Kaliyan and Morey, 2009). TMR feeds improve the

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availability of materials that are difficult to digest by unit animal through the microbial fermentation process, through the role of probiotics supplying beneficial microorganisms. Therefore, it can reduce the animal odor complaints caused by the open ventilation system and the storage of manure in the slurry ponds, which are the main causes of animal odor complaints against domestic pig farms. In addition, 12.1 pigs per sow are produced when TMR fermented feeds were fed. This is one more compared to the 11.1 pigs per sow generated when feeding general TMR feeds. Furthermore, the birth weight of piglets increased by 10%, resulting in an economic effect of 131.8 billion won per year (Cho, 2009). The determination of the physical properties of the main ingredients, Italian grass silage, tofu by-products, fermented roughage, and agricultural by-products, and a related basic investigation were conducted to study the technology for pellet molding using fermented TMR feeds for finishing pig farming. In this study, the pellet molding system for factor tests was designed and manufactured, and performance tests were conducted.

Materials and Methods

Sample preparation and property investigation

For better efficiency of pellet molding, it is important that the materials of TMR feeds are fed uniformly; however, the size of each material is different depending on the kind of material. In particular, various experiments were needed because the Italian rye grass (IRG) fermented feed used in this study was soft and contained a lower amount of lignin than woods. Table 1 lists review items for improved conditions for pellet moldability. The moisture content and moldability of pellets were controlled using water and treacle when necessary to improve pellet efficiency.

On the other hand, for the design and production of a pellet forming system using pork TMR feed, TMR feeds were prepared and their properties were determined. TMR feeds for pigs are formulated using diverse feed sources, and their physical properties change depending on the feedstock. In this study, the combination of the mixed feed, the IRG fermentation feed, and the "MR feed for Omega-3 pigs"prepared to match the fatty acid balance for pork at G farm in Chungnam Province were used as the official materials. The length of feedstuffs and the moisture content, density, and repose angle of TMR feeds were studied.

TMR1 (70% of compound feed and 30% of IRG)

The simplest way to feed fermentation forage to pigs in the form of TMR is to mix the compound feed and the grass-based fermented feed at a constant mixing ratio. According to the results of the livestock academy (Cho, 2009), the productivity of IRG-pelleted feed (moisture

Figure 1. Demolition of round bale and chopping of IRG silage (Hong et al., 2013)

Table 1. Review items for the improvement of pellet moldability

Improvement condition	Pellet process condition of TMR feed for pig	Necessary preprocess technique to develop
Kinds of materials: composition ratio of lipids, fiber, and treacle	TMR feed for pigs and normal or fermented feedstuffs (cut and softened) at a ratio of 7: 3 to 9: 1	Grain-based materials: adhesive, molasses; wood-based materials: lubricant, oil
Moisture content of materials: wood-based materials have the best formability when moisture content was approximately 15%	The best at approximately 15%	When mixing materials, it was necessary to adjust water content of each material
Size and uniformity of each material	Grain-based materials: less than 5 mm; grass-based materials: less than 3 cm	Molded with reinforced concrete structure

content 15% w.b.) was proper at 10% addition of sowing, and there was no significant problem at 20% and 30% addition. Therefore, in this study, the addition level of IRG silage (M.C. 60% w.b.) in TMR feed was 30% of the maximum in the building standard for sows. Figure 1 shows the sieving and softening of the IRG silage in the shape of a round bale, which was cut into 3 cm lengths. The amount within the 3 cm length was observed to be more than 95% (Hong et al., 2013). The silage in the shape of a round bale was dismantled and then cut to a certain length (Fig. 1). The chopped and softened IRG silage was put into a TMR mixer (Zebra, Livemac Co. Ltd., Gimje, Jeollabuk-do, Rep. Korea), and blended together with other compound feeds. The softening process and the shape of the blended TMR feed is shown in Figure 2.

The size of TMR feeds has a very large effect on the performance of the pellet. In particular, the pieces of the forage were long, which could interfere with pellet molding. Therefore, in this study, particles were further refined using a separate hammer mill (PM120, Buskirk Engineering, Ossian, IN, USA), as shown in Figure 3. As a result of grinding, the size of the forage particles was 1.5 cm on average.

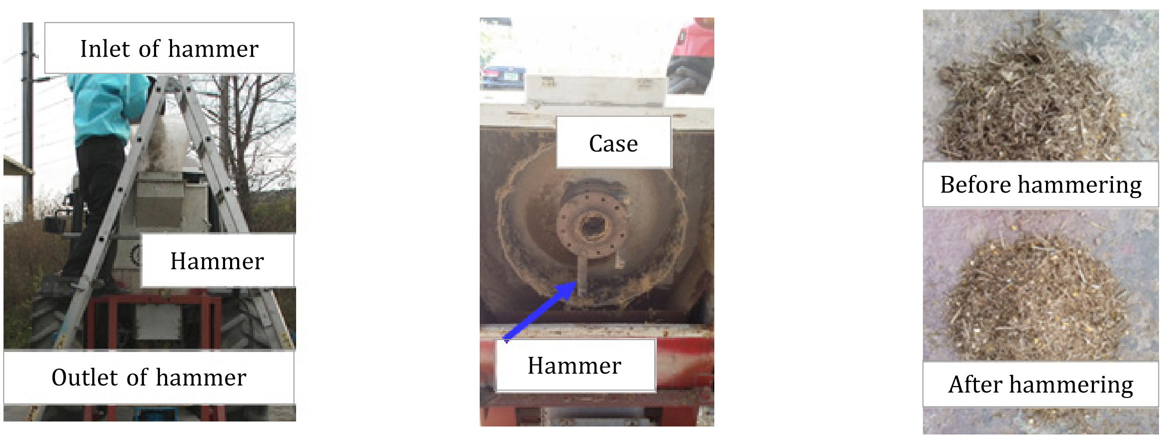
TMR2 (compound feed 30%, fermented forage 30%, grains 15%, food by-products 10%, other feeds 10%, fermentation agent 5%)

The G farm in Chungnam, which is the experimental farm in this study, partly used the by-products from the surrounding area as feed, and in particular, had been using the by-products of the food and drug companies for raising pigs without antibiotics. As a result, TMR2 feeds were prepared with 30% compound feed, 30% fermentation forage, 15% cereal, 10% food by-products, 10% other feed, and 5% fermentation agent. The length of the forage was 1.5 cm on average using the same TMR making process as described above for TMR1.

Measurement of moisture content, density, angle of repose

Moisture content was measured three times for each of 5 g of two test materials using quick mode (minimum scale 0.01%, accuracy 0.05% /min) using a moisture meter (MX-50, A&D Company Ltd., Tokyo, Japan). The density was measured three times by weight (g) of two 1000 ml beakers with the unit of kg/m^3. The angle of repose was determined by flattening the two test

Figure 2. Softening the chopped IRG silage, TMR mixing, and the resulting TMR feed (Hong et al., 2013)



(a) Photo of hammering (b) Internal part of the hammer (c) Shortened TMR feed

Figure 3. Shortening the softened TMR feed with a hammer mill

materials on a stainless steel square tray (54 × 42 × 5 cm) by the height of a rectangular tray and then lifting the square tray from the bottom to measure the angle (°) just before the TMR feed. This study was applied to the design a TMR fermented feed pellet molding system for pigs.

Manufacturing and performance test of pellet molding systems

Configuration of pellet molding system

Standard pellet feed molding system specifications for pig farmers were determined to confirm the power required for the standard molding device of the starter performance test. The required power was defined as the power to compress the material between the die and roller at high temperature and high pressure for molding of the pellet. The required power for molding (kW/100 kg/h) = 5 + 3 × (target production/100), and the power (kW/100 kg/h) required to produce 500 kg in 1 h operation was 5 + 3 × 500/100 = 20 kW for the standard system. For the system to produce 1000 kg/h, 5 + 3 × 1000/100 = 35 kW may be required. The required power for the standard system was 22 kW and 1800 rpm. In this study, the production of 500 kg/h was targeted, and the driving power source was a motor driven type of 22 kW and 1800 rpm. A standard pellet molding mechanism was developed to process a molding tool through which a pellet molded product passes through a circular iron plate. The material sandwiched between the die and rolls was pressed on the die fixed to the rotary roll at a high temperature and a high pressure while touching the circular plate. Pellets were manufactured with various pellet diameters ranging from 6 to 10 mm. The thickness of the die was designed and fabricated on the basis of 50 mm with a rotation speed from 175 to 250 rpm. In the case of pellets having a diameter of 10 mm only, a 30 mm thick die was further prepared and tested. The standard pellet molding mechanism could be applied as a pellet molding device in a flat-die type design. As shown in Figure 4, a molding tool through which a pellet molded article passes was machined into a circular steel plate. The material sandwiched between the circular plates was pressed onto a die fixed with a rotary roll at high temperature and high pressure. In long-term use, as shown in Figure 5, wear of the part ① was severe compared to part ②, and when the roll was rotated, the material was concentrated in part ①, and a difference in the relative pressure contact distance between the roller and the die occurred. To prevent such a difference, the contact method was improved such that the contact between the roller and the die was uniformly improved. The overall apparatus height was lowered by improving the application degree by structurally designing the material to flow in accordance with the rotation of the apparatus.

Shortly after the pellet was molded, the pellets were cooled at high temperature to prevent the pellet from breaking down because of crumbling of the pellet or high moisture content. While the discharged pellets were being moved through the conveyor, the blowing fan was operated to perform the cooling.

Production of prototype and performance test

Figure 6 shows the completed pellet molding system. In addition, a pellet molding system was equipped with pre-treatment and post-treatment equipment for the pellet performance test. Prior to the test, the particle size and moisture content of the TMR feed were measured, and the density and PDI (pellet durability index) of the pellets were also measured. The moisture content of the TMR feed was measured using an MX-50 moisture meter.

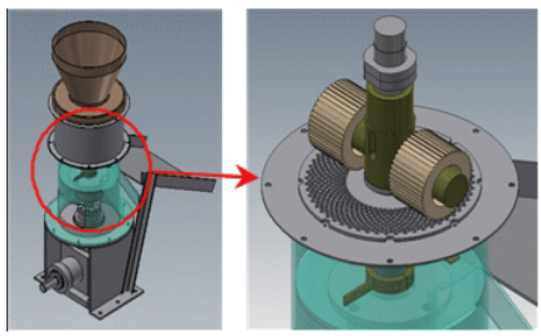


Figure 4. Flat-die type pellet molding machine

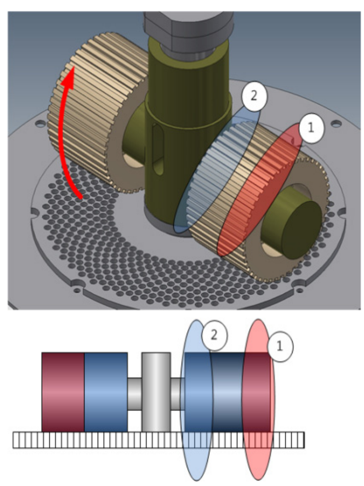


Figure 5. Image of rotary rolls and flat die for equal contact

The PDI of the pellet was measured using a durability tester and the procedure described in ASAE standard S269.4 (ASAE Standards, 2003). The durability tester consisted of two square boxes fixed on the rotating shaft. Two 500 g pellet samples were screened separately on a 5.6 mm US standard sieve. After tumbling at 50 rpm for 10 min, the pellets that were retained on the sieve and were sieved with the 5.6 mm screen for 30 s to remove the fines or broken pellets. The PDI was calculated using equation (1).

$$PDI\,(\%) = \frac{\text{mass of pellts retained on the 5.6 mm sieve after tumbling}}{\text{mass of pellets before tumbling}} \times 100 \quad (1)$$

To minimize the evaporation loss of the moisture content of the feed compounded in the TMR mixer, it was measured with H+6. The TMR feeds were stored in the feed conveyor hopper and then transported through the auger. The feed rate was set equal to the pellet production. The transferred TMR feedstock was poured on top of the pelletizer body to compress the material with a compression roller having a die hole of 6 to 8 mm and a die thickness of 5.5 mm. The average output DC voltage (V), average output current (A), and pellet production (kg/h) were measured in triplicate for 30 s for each rpm set of 85, 116, 135, 148, and 184 rpm of the rotation speed in a compression roller drive. The produced pellets were transferred to a belt conveyor and two dry fans were installed to facilitate storage management. The performance of the prototype system was evaluated with the maximum yield, PDI, and moisture content depending on the moisture content of the TMR compound feed and the speed of the pelletizer rotary shaft. The pellet molding apparatus contained the feed supply, pellet manufacturing, and dry transfer. The TMR feeds (30% compound feed, 30% agricultural by-product, 15% cereal, 10% food by-product, 10% other feed, and 5% fermentation agent), which were being fed at G farm, were mixed for 30 min using the TMR mixer installed in the existing farm.

Results and Discussion

Properties of TMR feed

Table 3 lists the results of the physical properties of TMR1 feed measured as a disclosure material. The moisture content was 31.6% (w.b.) on average, which was less than that of general haylage from 40 to 60%

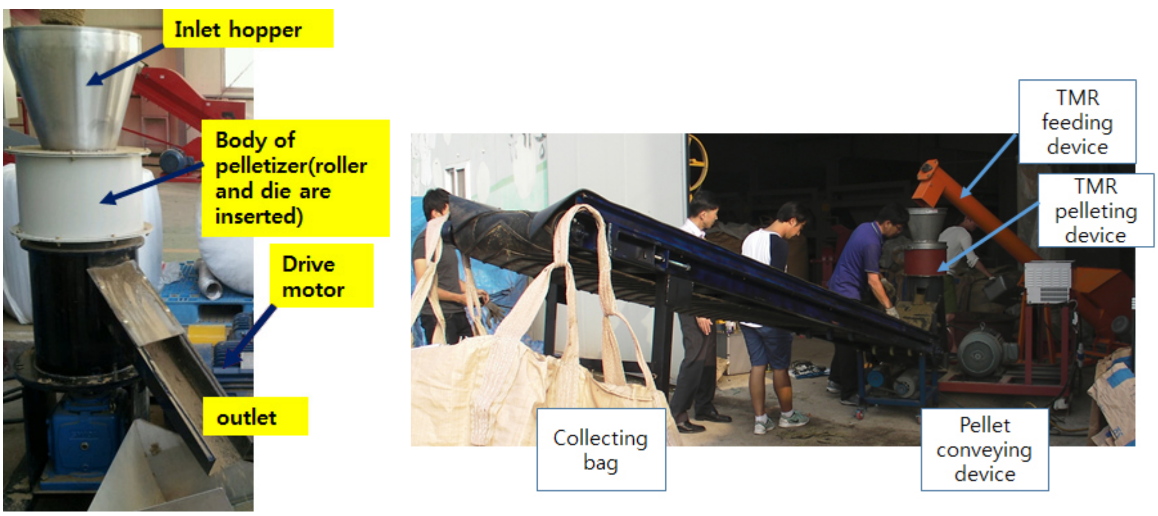


Figure 6. Developed pelletizer and TMR pellet manufacturing system installed in pig farmhouse site

Table 2. Physical properties of the pellets using TMR1 (70% compound feed and 30% chopped IRG silage).

Replication	Moisture content (%, w.b.)	Density (kg/m^3)	Angle of repose (°)
1	29.5	400	53
2	31.2	380	49
3	34.2	380	51
Average	31.6	387	51

(w.b.). The average density was 387 kg/m^3, indicating that the density decreased as the amount of forage increased. The measured physical properties were used as the basic data for the design of the pellet molding device.

Table 4 lists the physical properties of the TMR2 feed measured as disclosure material. The average moisture content was 22.2% (w.b.), which was lower than that of the TMR1 feed. The average density was 544 kg/m^3, which was higher than that of the TMR 1 feed because the amount and length of IRG silage forage were low and relatively short.

Performance test results of prototype pellet molding system

Feeding technology

The compounded feed in the feedstock did not need to be inserted into the feeder, which was placed at the front of a pulverizing process, because it was already pulverized and was heavy in weight relative to its volume. In the case of fermented feedstuffs or hay, it was possible to feed without any major problems when the moisture content was between 15% and 50%, but it was difficult to control the feedstock for a long time if taken to cut its fiber by a hammer mill. When the moisture content was less than 15%, it could be easily inserted as it was crushed and cut in the subsequent crushing process. However, when the moisture content was lower, the amount of dust was greatly increased, thereby maximizing the shearing effect and suppressing the generation of dust. It was judged that the design of the feeding device to control the feed amount by grasping and feeding the crushed hay feed would be necessary.

Grinding technology

Hay was crushed relatively easily into a high-speed rotary impact mill at the 3000 rpm level. However, it was judged that it was necessary to make the hammer mill method suitable for crushing the tough and long hay by adding the function of cutting in the form of a shear blade to the hammer mill method. In addition, the hay was cut into 5 cm pieces after being subjected to the crushing and cutting process once, so that it was necessary to adjust the rotating speed of the crusher to a level of cutting the crusher to a length of approximately 2.5 cm. Table 5 shows the comparison of the pulverization performance depending on the moisture content of feed materials. The dehumidification effect of the pulverization was measured at approximately 2%.

Pellet molding technology

Moldability was evaluated depending on the feed materials and their moisture content. The moldability of each ingredient was excellent when the content of fat and protein was high, whereas the hardness after molding was high when the materials were difficult to mold because of the high content of fiber. However, when the compound feed ratio was higher than 90%, it was considered that hard pellet molding, such as wood pellets by lignin denaturation, was not easy. The moldability depending on the moisture content of the feed materials, was evaluated when the moisture content after mixing with the mixed feed and hay was the most suitable within 15~25%. At less than 15% of moisture content, it was impossible to mold, and dust was generated by additional dry pulverization because of the high temperature and the

Table 3. Physical properties of the pellets using TMR2 (30% compound feed, 30% agricultural by-product, 15% cereal, 10% food by-product, 10% other feed, and 5% fermentation agent).

Replication	Moisture content (%, w.b.)	Density (kg/m^3)	Angle of repose (°)
1	22.29	543	47
2	22.23	526	52
3	22.08	564	50
Average	22.2	544	50

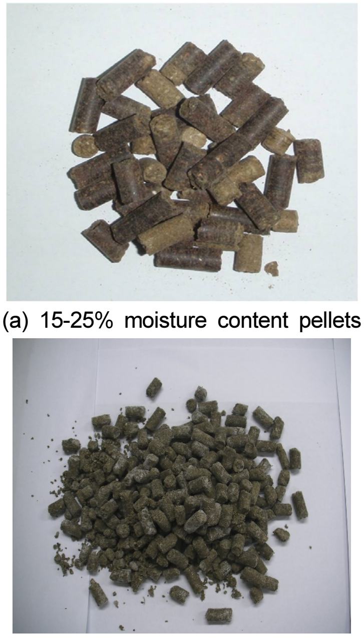
Table 4. Comparison of crushing performance.

Crushing performance	Moisture Content (%)		
	25	20	15
Grinding size (avg. mm)	15	10	5
Residence time (min)	10	7	5

separation of feed materials. In addition, it was judged that the moisture content of 25% or more was difficult to use because of the pellet shape and hardness because of atheroma (Figure 7).

The particle size of TMR feed was composed of 3.3 mm (2.40%), 1.4 mm (43.33%), 1.18 mm (9.68%), 1 mm (3.85%), and remaining amount (40.74%) (Table 6), and the volumetric density was 544 kg/m^3.

The production capacity per unit was 0.5 ton/h, the standard required power was 22 kW at 1800 rpm, and the power source was composed of a 380 V 3-phase standard. The angle of repose was approximately 45 to 50° to feed TMR compound feed to the upper pellet hopper part smoothly. In addition, when the TMR compounded feed was pressed on the compression roller, it was judged that the size of 7 mm or more would be most suitable because the die hole became clogged when it was less than 7 mm. It is necessary to preheat during the molding process. It was the suitable time to pellet the TMR compound feed when the white steam was visible in the hopper section after heating the appropriate amount of TMR compound feed for 30 min at 90~100°C in the outer tube. The rotation speed of the compression roller was most suitable for preheating at approximately 70 to 80 rpm. As shown in Tables 7 and 8, the pelleting rates of TMR1 feed (70% compound feed and 30% IRG) and TMR2 feed (30% compound feed, 30% agricultural by-products, 15% cereal, 10% food by-product, 10% other feed, and 5% fermentation agent) increased as the rotation speed increased, and their moisture contents were reduced by approximately 2% by pellet molding. The optimal range of the moisture content for optimal pellet performance was in the range of approximately



(a) 15-25% moisture content pellets

(b) Over 25% moisture content pellets

Figure 7. Produced pellets with different moisture content

Table 5. Particle size test result (TMR2 feed)

Replication	Sieve (mm)					Total weight (g)
	3.35	1.4	1.18	1	Remaining amount	
1	5.34	133.6	29.3	13.05	157.88	339.17
2	8.85	157.15	31.42	10.46	141.75	349.63
3	10.55	156.08	39.16	16.22	120.49	342.50
Average	8.25	148.94	33.29	13.24	140.04	343.77
Percentage	2.40%	43.33%	9.68%	3.85%	40.74%	100%

Table 6. Measurement results depending on rotation speed using TMR1 feed (70% compound feed and 30% IRG)

Rotation speed (rpm)	Moisture content (%)		Pelleting rate (kg/h)	Density		PDI (%)
	Input	Output		Pelleting(g/cm^3)	Bulk(kg/ m^3)	
85	18.10	16.55	311	1.10	581.26	94.05
116	18.10	15.37	451	1.00	591.27	95.13
135	18.10	16.21	502	1.00	588.76	93.85
148	18.10	14.82	577	1.10	582.55	91.64
184	18.10	15.77	657	1.00	590.86	92.62
Average	18.10	15.74	500	1.04	586.94	93.46

18%. The density and bulk density of pellets were not correlated with the rotation speed, and the PDI was not affected. However, the pellet throughput was increased by increasing the rotation speed. When the rotation speed was 85 rpm, the pelleting rate was from 311 to 320 kg/h, whereas it increased to the range of 657 to 744 kg/h twice or more when the rotation speed increased to 184 rpm. It appeared that the pellet throughput was influenced by rotation speed. The PDI and pellet throughput for TMR1 and TMR2 feed was 93.9% and 502 kg/h, and 94.2% and 536 kg/h at 135 rpm, respectively. In addition, the drying effect was verified by showing a moisture decrease rate of approximately 1.5 to 2.0% as the result of installation of two sets of cooling fans in the pellet conveyor (Table 9).

Conclusion

In this study, the physical properties and production factors of TMR compound feed were tested to gather basic data for the development of a pellet molding machine using TMR compound feed. Overseas research has focused on the technologies required for pellet molding of a single material or blended feed for fibrous materials, starch grains, high fat crops, and other industrial by-products as the main ingredients of feedstuffs for pigs. Therefore, based on overseas cases and trends, the pellet molding device and pellet production technology were conducted in the Rep. Korea. The main results are summarized as follows:

(1) The moisture content and density of TMR1 feed consisting of 70% compound feed and 30% IRG, were approximately 31.6% and 387 kg/m^3, respectively. The moisture content and density of TMR2 feed consisting of 30% compound feed, 30% agricultural by-product, 15% cereal, 10% food by-product, 10% other feed, and 5% fermentation agent, were approximately 22.2% and 544 kg/m^3, respectively. The moisture content, angle of repose, and bulk density of TMR1 and TMR2 feed, were applied to design the factor test device of the pellet molding system.

(2) The factor test of the pellet molding system was conducted to confirm the possibility of molding by verifying the technology of each driving system for manufacturing the prototype of the pellet molding system. The standard pellet molding system was constructed by selecting the motor method driven by electricity.

(3) The prototype of the pellet molding system was suitable for approximately 30 min at 90 to 100°C for the outer tube temperature and approximately 70 to 80 rpm of the rotation speed of the compression roller. As the rotation speed increased, the pellet molding throughput increased with the increase in

Table 7. Measurement results depending on rotation speed using TMR2 feed (30% compound feed, 30% agricultural by-product, 15% cereal, 10% food by-product, 10% other feed, and 5% fermentation agent)

Rotation speed (rpm)	Moisture content (%)		Pelleting rate (kg/h)	Density		PDI (%)
	Input	Output		Pelleting(g/cm^3)	Bulk(kg/m^3)	
85	17.56	16.15	320	1.2	592.28	94.23
116	17.56	14.92	468	1.1	597.72	95.31
135	17.56	16.03	536	1.1	592.96	94.20
148	17.56	14.03	536	1.1	587.57	90.94
184	17.56	15.60	744	1.0	595.96	92.85
Average	17.56	15.35	521	1.1	593.30	93.51

Table 8. Measurement of drying effect using cooling fan

Replication	Moisture content (%)	
	Input	Output
1	16.63	14.66
2	15.58	13.79
3	14.86	14.24
Average	15.69	14.23

the throughput, which was approximately 2.3 times at 184 rpm compared to 85 rpm. It was difficult to operate because of abnormal noise over 184 rpm.

(4) The yield of pellets with 94.2% PDI at 135 rpm was 536 kg/h, which was the optimal condition.

(5) It is important to maintain the feed moisture content and rotation speed of the pellet production system for the disclosed materials. If the main raw materials and their moisture conditions were changed, additional experiments on the raw materials would be necessary.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgement

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