Research Article

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Effect of Moisture Adjustment on Physico-chemical Properties, Durability and Production Efficiency of Broiler Feed Pellets

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Abstract

This study aims to investigate effect of moisture adjustment on physico-chemical properties, durability and production efficiency of broiler feed pellets. Three levels of moisture content (12, 13 and 14% wet basis) were adjusted by adding water at mixing step prior to pelletizing. The properties of pellets including moisture content, gelatinization behavior, pellet durability, density and length were determined. Moisture adjustment significantly increased moisture content of the final pellets ($p < 0.05$) but did not affect gelatinization behavior, pellet durability and density. The pellet length slightly decreased as the initial moisture content increased. Production efficiency was improved when increasing moisture content up to 14% while the quality of pellet remains the same. Thus, appropriate level of moisture adjustment at the mixing step could improve production efficiency of feed pellets.

Keywords: Broiler feed pellet, Gelatinization, Moisture adjustment, Quality, Production efficiency

1 Introduction

Broiler industry is one of the most popular agro-industries in Thailand. Chicken meat is a good source of protein which has the lowest price comparing with other meats. Thus, chicken meat is ranked number one for Thai people consumption. In 2014, the highest cost of broiler production is the feed cost, which contributes to about 60–70 percent of the total production cost. The raw material of broiler feed consists of cereal and protein that are necessary to the growth of broiler. Broiler feed generally consists of about 62 percent of corn and broken rice, 30 percent of soybean meal, 3 percent of fish meal and 5 percent of other ingredients. Corn and soybean meal are the main ingredients of broiler feed since corn is source of energy while

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soybean meal is source of protein [1]–[3].

The growth of each broiler also depends on feed intake. It is important to make broiler intake feeds at the optimum level and consistently. Aviatech [4] performed an experiment on effect of feed type (pellets and fine) on broiler weight gain. The result shown that broilers fed with 50 : 50 mixed feed got significantly higher weight gain than the broiler with 100 percent fine. Similarly, Abdollahi *et al*. [5] reported that the feed pellet durability could be increased by addition of binding agent. As pellet durability increased, the weight gains of 22–35 days old broiler increased.

Pelleting process or pelletization aims to agglomerate small particle of feed to become a large particle by using heat, moisture and mechanical pressure. The wet mash that has already been mixed with all raw materials is compressed through the die in machine called pellet mill to form feed pellets. There are two major processes to form pellets which are conditioning and pelleting. During conditioning, gelatinization partially occurs when steam is added to the mash. Moisture form steam makes starch within high carbohydrate content raw material swell while heat from steam tickers the gelatinization process. The mash is gelatinized again in pelleting step due to the friction force between partially gelatinized mash and die holes. To ensure that the main motor driven the pellet mill is not operated over load due to too high friction, California Pellet Mill Co. [6] suggested that amp meter should be installed as a part of electrical system in pellet mill in order to make it easy to control the mash feed rate to maximize the production capacity by machine operator.

Water can be added to pelleting process in several forms at 2 stages, i.e., mixing and steam conditioning processes but for different purposes. Water is generally added during wet mixing while steam is added at conditioning stage. Moisture added prior to pelleting aims to improve pellets durability by promoting gelatinization and lubrication during pelleting process [6]. There are several researches involved the benefits of moisture addition. Aviatech [4] and Abdollahi *et al*. [5] reported that level of moisture added before conditioning and conditioning temperature significantly affected degree of starch gelatinization. Moritz *et al*., [7], [8] reported that normally, increasing of moisture prior to pelleting in corn-soybean based diets bring about increasing of starch gelatinization. Moritz *et al*. [8] also reported that addition of water can significantly increase production rate. Abdollahi *et al*. [9] revealed that moisture decrease friction heat and reduce extent of gelatinization. However, these researches added totally different moisture to each feed mash treatments to observe the change of the properties. In the real production, the manufacturer not allowed to adjust moisture in wide range. Thus, the effect of moisture adjustment in narrow range is interested to investigate. As stated earlier, water is one of the most important factors in pelleting process. During storage period, the moisture content of raw material may be lost.

Most factories are using experienced operators to manually adjust for optimum moisture content. Furthermore, the lack of in-depth knowledge may lead to waste of time and money due to trial and error. This research aims to understand the effects of moisture level adjustment on physical and chemical properties, durability and production efficiency of broiler feed pellet by maintaining the quality of the final product as standard.

2 Materials and Methods

2.1 *Experiment apparatus*

Broiler feed pellets were supplied by a broiler feed mill factory in Lopburi province, Thailand. Main raw materials were corn (39%), soybean meal (28%), wheat (25%) and fat and other (8%). The feed pellets were prepared by grinding raw materials with a hammer mill (3 mm sieve size) before mixing. Dry ingredients were mixed until well-mixed condition was achieved before wet ingredients were added. Water was added to the wet mixing step in order to obtain 3 levels of moisture adjustment, i.e. 12, 13 and 14% wet basis. After mixing, the mash was passed through a pellet mill (Pellet mill DPHD, Bühler, Uzwil, Switzerland). The feed rate was adjusted between 38–42 ton/h. Then, the feed pellets were cooled down immediately to approximately 32ºC by an ambient air in a cooling chamber before sizing and packing. The samples were collected at 2 stages which are after mixing (mash) and before packing (feed pellet) for further analyses. The determination of physico-chemical properties and durability were conducted in 2 replications with 3 subsamples for each treatment condition.

Determination of degree of gelatinization was originally described by Zong-qiang *et al*. [10] and Jovin *et al*. [11]. Feed mash and feed pellets were undergone size reduction separately by milling in a mortar and sieving with 500 µm sieve pan (Retsch, Germany). Then, 2.5 mg of fine samples was put into a stainless steel DSC pan before filling with 7.5 µL of DI water. The stainless steel pan was hermetically sealed prior to aging at room temperature (around 25ºC) for 3 h. After that, the analysis was conducted by a differential scanning calorimeter, DSC (DSC 8000, Perkin Elmer, MA, USA) at the temperature range of 20–120°C and the heating rate of 10°C/min. Degree of gelatinization was calculated by using Equation (1).

$$GD = \left[\left(\Delta H_{ns} - \Delta H_{ts}\right) / \Delta H_{ns}\right] \times 100\% \quad (1)$$

Where ΔH_{ns} and ΔH_{ts} are melting enthalpies of mash and pellet samples, respectively.

Pellet Durability Index (PDI) was determined by putting 500 g of feed pellets into a tumbling box and spinning at 50 rpm for 10 min. After tumbling, the pellets were sieved with 3.35 mm sieve pan. The weight of the pellets left on the pan was determined. Pellet durability index was calculated from the ratio of remaining pellets and total pellets before tumbling [12], [13]. Pellet hardness was analyzed by diametrical compression with texture analyzer (TA-XT2, Stable Micro Systems, NY, USA). The length of each pellet sample was controlled at the average of 7.5±0.2 mm. The sample was placed horizontally on the texture analyzer plate and compressed by 50 mm diameter stainless steel cylindrical probe. The texture analyzer was calibrated with 5 kg standard load. The test speed and trigger force were set at 0.16 mm/s and 50 g, respectively. Stress at failure and E-modulus were calculated for every single pellet. The average hardness value was obtained from 15 pellets [14].

Unit density was determined by using resin replacement technique. Ten milliliters of cation resin were poured into a cylinder then and weighed. After that, 15 pellets were filled and mixed with the resin in the cylinder. The increased weight and volume were recorded as the weight and volume of pellets. The unit density was calculated as mass divided by volume [12]. Bulk density was obtained by pouring pellets into a cylinder until 40 mL mark was reached. Weight of pellets was measured to calculate bulk density as mass divided by volume [12].

Image analysis was used to determine size of 100 pellets by using ImageJ software (ImageJ 1.50b). The pellets in a tray were captured with the Vernier caliper. The length of each pellet was converted from pixel to millimeter using the conversion value obtained from the Vernier caliper included in the image [15].

Near infrared (NIR) spectroscopic technique (FOSS NIRSystem, 5000) was used to determine chemical composition, including moisture content, protein, fat, fiber, carbohydrate and other, of mash and feed pellet samples.

Energy consumption in pelleting process was obtained by collecting the electrical current drawn by the main motor that drives the pellet mill during pelleting. The electrical current in terms of Ampere (A) was collected by an amp meter. The power was calculated over time for the entire batch of production. The specific energy consumption was obtained by dividing the total energy consumed by the main pellet mill motor (kWh) by the total production volume (ton) during that period.

To study the effect of moisture adjustment, the experimental data were analyzed and presented as mean value with standard deviations. ANOVA and Duncan's multiple range tests were used to compare means at an α-level of 0.05 using SPSS software (SPSS 16.0).

3 Results and Discussion

3.1 *Effect of moisture adjustment on chemical composition of feed pellets*

Mashes with different levels of moisture adjustment were collected after the mixing process completed and analyzed for their chemical composition as presented in Table 1. The actual moisture content and other chemical compositions of all samples were measured by near infrared spectroscopy technique. The result showed that the moisture content (wet basis) of 12% and 13% formulas were higher than the expected levels while 14% formula did not reach the target moisture content. The moisture contents of all treatments were significantly different ($p < 0.05$). These errors could be explained by the limitation of large scale pelleting process that does not allow wide range of moisture adjustment before conditioning and pelleting processes. Other compositions including protein, fat,

Table 1: Effect of moisture adjustment on chemical composition of mash

Level of Moisture Adjustment	% Wet Basis	% Dry Basis			
	Moisture Content	Protein	Fat	Fiber	Carbohydrate and Others
12%	12.68^{a}±0.17	24.92±0.51	4.09±0.16	4.04±0.11	66.95±0.59
13%	13.13^{b}±0.24	25.53±1.18	4.03±0.12	4.12±0.16	66.31±1.31
14%	13.60^{c}±0.06	24.86±0.59	4.21±0.09	3.98±0.10	66.95±0.54

Different superscript letters (a, b, c) indicate that the values in the same column are significantly different ($p < 0.05$).

Table 2: Effect of moisture adjustment on chemical composition of feed pellet

Level of Moisture Adjustment	% Wet Basis	% Dry Basis			
	Moisture Content	Protein	Fat	Fiber	Carbohydrate and Others
12%	12.35^{a}±0.09	22.53±0.25	7.06±0.49	2.73±0.17	67.68^{b}±0.48
13%	12.42^{a}±0.14	22.62±0.47	7.19±0.17	2.84±0.09	67.36a^{b}±0.37
14%	12.59^{b}±0.12	22.90±0.30	7.41±0.24	2.94±0.10	66.85^{a}±0.48

Different superscript letters (a, b) indicate that the values in the same column are significantly different ($p < 0.05$).

fiber, carbohydrate and etc. were presented in dry basis to ensure that there was no significant difference in solid content of the mashes. The result showed that there was no significant difference among all main components obtained from the three treatments ($p > 0.05$).

The chemical composition of feed pellet or the finished products are presented in Table 2. Increasing level of moisture adjustment resulted in an increase in the final moisture content of feed pellets. However, the difference in moisture content among the feed pellets was much smaller than that of the mashes obtained from all treatments due to the cooling effect. Total moisture can be defined as bound moisture which is the initial water in ingredients and added moisture from steam condensation and water added at mixing step [6]. Skoch *et al*. [16] reported that most of the moisture added in steam conditioning step would be completely removed in cooling step. It was analogous to presumption of Moritz *et al*. [17] that during pelleting at pellet die or cooling, high amount of free water would be more efficiently flashed off. However, moisture adding in mixing step provides better permeation of water to starch granules and limits moisture added by steam [6], [9]. Then, the steam condensate added was completely removed with some of the water added at mixing step. Therefore, the final pellet moisture content was still close to that of the mash. Therefore, water added to the mash during mixing step affected quality of the final pellets in terms of moisture content. Carbohydrate and other components of final pellets were slightly decreased when moisture level adjustment was increased ($p < 0.05$) because of the increasing of other compositions including protein fat and fiber. Although those compositions were not significantly different, it tended to increase and affected total solid content.

3.2 *Effect of moisture adjustment on gelatinization behavior of pellets*

Gelatinization curves or thermogram of mash sample and feed pellets formulated with 12, 13 and 14% initial moisture adjustment obtained from DSC are presented in Figure 1.

Mash and feed pellet samples with initial moisture content of 12, 13 and 14% had different areas under curve. For all samples, only a single endotherm was observed. The endotherm size or the peak height of the mash was the largest because mash did not pass through conditioning and pelleting steps which induce starch gelatinization. Thus, it required the highest amount of energy to complete gelatinization process. On the other hand, the feed pellets with 12, 13 and 14% initial moisture adjustment yielded smaller endotherms than that obtained from the mash. The difference in peak height indicated that different levels of moisture adjustment resulted in different degrees of gelatinization of feed pellets during conditioning and pelletizing. Degree of gelatinization of the pellet samples was determined using Equation (1).

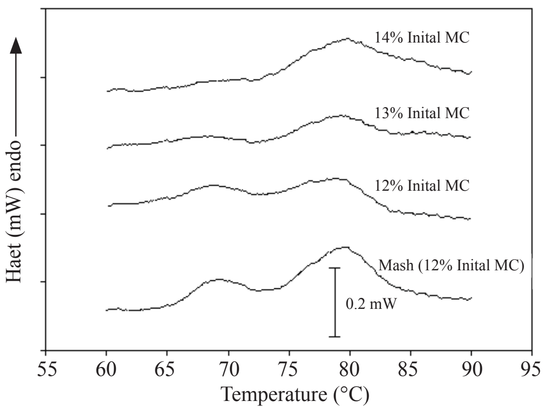

Figure 1: Differential scanning calorimeter (DSC) thermogram of mash sample, feed pellets with 12, 13 and 14% initial moisture adjustment.

The enthalpy of melting was obtained from an area under the thermogram plotted between heat flow and temperature. Assuming that the mash had zero degree of gelatinization and required maximum energy input to completely gelatinized, the degree of gelatinization was obtained by dividing the difference between the melting enthalpy of the mash and the feed pellet by the melting enthalpy of the mash and reported in percentage. From Table 3, the initial moisture adjustment levels of 12–14% were not high enough to completely gelatinize the feed pellets. Although, the pellets with 13% moisture adjustment had the highest degree of gelatinization, there was not significantly different from the degrees of gelatinization obtained from the feed pellets with 12 and 14% moisture adjustments ($p < 0.05$). Moritz *et al*. [7], [8] reported that normally, increasing of moisture content of the mash prior to pelleting in corn-soybean based diets brought about increasing of starch gelatinization. Unlike, the previous studies by Moritz *et al*. [7], [8], no correlation between level of moisture adjustment and degree of starch gelatinization was observed. This disagreement could be due to non-uniformity of moisture distribution of the mash prepared by industrial scale mixer.

In addition, there are two parameters related to temperatures that represent gelatinization behavior. Onset temperature shows the start point of gelatinization and Peak temperature shows the highest energy required point of gelatinization. These temperatures are thermal transitions that associated with enthalpy of starch gelatinization in terms of area under peak [18]. Sometimes the temperature and the degree of gelatinization are correlated by physical properties. However, the result shows that initial moisture content had no effect on both onset and peak temperatures ($p < 0.05$). Jovas *et al*. [11] reported that enthalpy of starch gelatinization caused by disruption of starch granule structure during milling process and the peak temperature was strongly correlated with the particle size. Abdolahi *et al*. [9] suggested that adding of moisture could decrease friction force in die holes during pelleting process but it also reduced the extent of starch gelatinization. In contrast, when moisture content decreased before pelleting, high friction force effects would arise and resulted in over load of pellet mill motor. However, Lundblad *et al*. [19] found that adding more water could also cause the blockage of pellet mill due to slippage of rollers.

Table 3: Effect of moisture adjustment on gelatinization temperature of feed pellets

Samples	Peak Temperature (ºC)	Enthalpy of Melting (J/g)	Degree of Gelatinization (%)
Mash	78.18±4.10	4.02±0.56	-
12%	78.32±0.97	2.57±0.40	33.76±20.10
13%	78.61±1.35	1.46±1.01	62.47±25.22
14%	78.56±1.08	2.14±0.62	47.01±12.68

3.3 *Effect of moisture adjustment on pellet durability*

3.3.1 Pellet Durability Index (PDI)

Pellet durability index or PDI was defined as endurance of pellets that remain intact until the time for feeding either the pellets were stacked while storing or tumbled during transportation [9]. The result in Table 4 shows that the moisture adjustment had no effect on PDI ($p > 0.05$). However, feed pellets with 13% initial moisture adjustment tended to have the highest PDI which is agreeable to its gelatinization behavior in the previous section. The gelatinized starch acts as a binder and fostered the adhesion forces among the granulated particles making the pellets more durable [20]. This finding went along with the studies of Skoch *et al*. [16] and Moritz *et al*. [7], [8], which indicated that an increase in degree of gelatinization resulted in an increase in pellet durability.

Table 4: Effect of moisture adjustment on pellet durability index and hardness

Level of Moisture Adjustment	Pellet Durability Index (%)	Pellet Texture	
		Hardness (g)	Stress Failure (kPa)
12%	92.67±1.03	2189±363	630±110
13%	93.00±1.10	2042±353	577±104
14%	92.00±0.00	2182±377	625±112

3.3.2 Pellet hardness

Pellet hardness is another important indicator of pellet qualities suggested to measure along with PDI [9]. Hardness is defined as the amount of force required to crush the pellet [21]. Stress failure is used to describe the pressure or force per unit area that causes the sample to collapse. Thus, it can be calculated based on hardness value by dividing the hardness or maximum force to break the pellet (N) by the surface area of the probe (m^2) [14]. Although, the feed pellets with 13% initial moisture adjustment tended to have the lowest hardness, there was no significant difference in pellet hardness obtained from 3 levels of moisture adjustment (Table 4). Normally, moisture addition can increase degree of gelatinization which results in improvement of pellet durability. However, an increase in degree of starch gelatinization may not always be accompanied by an increase in pellet durability. Parsons *et al*. [22] also found that the pellet with binder in its formula created a greater hardness than the pellet with added water, while the PDIs of both pellet formulas were similar. The possible explanation of this phenomenon is that relationship between gelatinization and pellet durability may also depend on location of gelatinized starch. Gelatinized starch distributes evenly thorough the whole pellet may be more effective in binding all particles together than large amount of gelatinized starch clustering in the center or some parts of the pellet [17]. Thus, the feed pellets with higher degree of gelatinization might be softer than the ones with lower degree of gelatinization due to the distribution of gelatinized starch was more even in the former case. Nevertheless, all level of moisture adjustment resulted in no significant difference in pellet durability in terms of PDI and pellet hardness ($p < 0.05$) as shown in Table 4.

3.4 *Effect of moisture adjustment on pellet density*

Pellet density could represent particle size of ground materials used for producing feed pellets. Reducing size of ground materials before pelleting brought about improved quality, increased production rate, increase bulk density, greater horsepower efficiency and longer die life [6]. Normally, natural protein plays an important role as a plasticizer under heating during conditioning and pelleting processes. Thus, high density and production rate can be expected from raw material that contains high amount of natural protein [6], [23]. From Table 5, unit and bulk densities of feed pellets obtained from all treatments were not significantly different ($p < 0.05$). In other words, moisture adjustment in the range of 12–14% (wet basis) had no effect on the pellet density.

Table 5: Effect of moisture adjustment on unit and bulk densities of feed pellets

Level of Moisture Adjustment	Unit Density (kg/m^3)	Bulk Density (kg/m^3)
12%	1255.9±91.56	623.42±29.62
13%	1223.7±81.40	633.79±19.58
14%	1274.9±76.46	622.38±8.89

3.5 *Effect of moisture adjustment on pellet length*

After the mash was compressed into die holes, feed pellets were formed and cut into rod-shape by cutting tools located near the outer surface of ring die. The distance between the ring die surface and the cutting tools was set to the maximum length of pellets. However, most pellets were broken before approaching the cutting tools. Pellet size distribution obtained from each treatment was showed in Figure 2. Since the distribution of pellet length could not be represented by normal curve, the median and box-plot was chosen to determine effect of moisture adjustment on pellet length. By increasing the moisture level, the pellet length slightly decreased.

3.6 *Effect of moisture adjustment on energy consumption of pellet mill*

The electrical current drawn by the pellet mill was monitored by an amp meter and recorded over time to calculate the energy consumption. Figure 3 represents

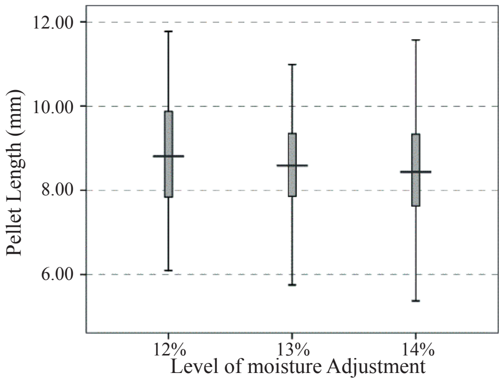

Figure 2: Effect of moisture adjustment on pellet length.

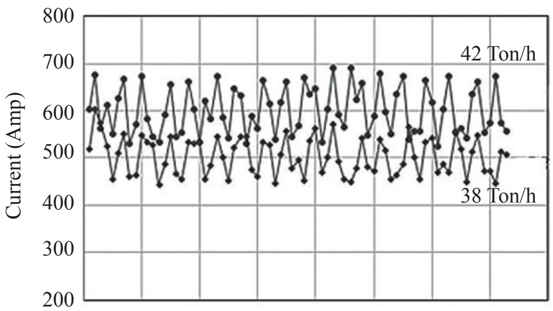

Figure 3: Effect of feed rate on current profile of pellet mill in 13% initial moisture adjusted pellet.

the current profile during pelletizing the mash with initial moisture content around 13% at the production rate of 38 and 42 ton/h.

Increasing the production rate from 38 to 42 ton/h resulted in much higher current drawn by the pelletizer (Table 6) and higher specific energy consumption (Table 7). From machine specification, the maximum current that can be supplied to this pelletizer before the breaker is tripped is 700 A. The result showed that the mash with 12% initial moisture adjustment consumed higher current when the feed rate was increased. However, the mash with 12% initial moisture adjustment could not be fed at the highest feed rate as 42 ton/h. At 12%, moisture content in mash might be too low leading to much increase in the friction force in die holes during pelletizing. The increased friction force caused the blockage of die holes and over load of motor which tripped the breaker. In comparison with 13% initial moisture adjustment, the maximum feed rate of 42 ton/h was obtained at 700 A. The result agreed well with Moritz *et al*. [8], which reported that an addition of water could significantly increase production rate. Although the feed rate and current drawn by the pellet mill were not determined for 14% moisture adjustment, it was suspected that at the feed rate of 42 ton/h, the pellet mill should consume less than 700 A due to the lubricating effect of moisture in mash. Although Lundblad *et al*. [19] found that adding more water could cause the blockage of pellet mill due to slippage of rollers, California Pellet Mill Co. [6] suggested that the choke point of pellet mill is around 18% of total mash moisture. Therefore, below a choke point, an increase in mash moisture can improve the feed rate and reduce the specific energy consumption.

The specific energy consumption was calculated from electrical current which is recorded by an amp meter in pellet mill system during conditioning and pelleting process divided by the feed rate of this process (Table 7). At both feed rates of 38 and 42 ton/h, the mash with 13% initial moisture adjustment had lower energy consumption than the mash with 12% moisture adjustment, which means 13% initial moisture had greater efficiency. For 14% moisture adjustment, the specific energy consumption was expected to be lower than the other treatments due to lower friction force.

Table 6: Effect of moisture adjustment on maximum current of pellet mill

Water Level Adjustment	Maximum Current (AMP)		
	Feed Rate 38 ton/h	**Feed Rate 40 ton/h**	**Feed Rate 42 ton/h**
12%	642	650	Not feasible
13%	602	Skipped	700
14%	N/A	N/A	N/A

Table 7: Effect of moisture adjustment on specific energy consumption of pellet mill

Water Level Adjustment	Specific Energy Consumption (kWh/ton)		
	Feed Rate 38 ton/h	**Feed Rate 40 ton/h**	**Feed Rate 42 ton/h**
12%	5.64±0.46	5.69±0.48	Not feasible
13%	5.06±0.40	Skipped	5.21±0.46
14%	N/A	N/A	N/A

4 Conclusions

Addition of water or moisture content adjustment altered enthalpy of melting in feed pellets. However, initial moisture adjustment had no significant effect on degree of gelatinization of the feed pellet, pellet durability in both of hardness and PDI values ($p > 0.05$). Pellet length tended to decrease when moisture adjustment increased.

Although an initial moisture adjustment had no significant effect on some physical and chemical properties due to uncontrollable factors in an industrial scale production process, improvement of the production efficiency had been achieved. By increasing the initial moisture content to 13%, the feed rate of pellet mill could be increased to 42 ton/h, while only 40 ton/h was achieved when increased the initial moisture content to 12%. The higher initial moisture content resulted in the higher production rate and lower specific energy consumption because of the lubricating property of water.

In an industrial scale production, there were a lot of uncontrollable factors that might directly affect properties of feed pellets. Thus, further experiment should be conducted in a laboratory scale in order to understand effect of process parameters of interest and minimize the production loss before applying the knowledge to improve the pellet quality and production efficiency in an industrial scale production.

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