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Effect of Grain Moisture Content and Roller Mill Gap Size on Various Physical Properties of Yellow Dent Corn Flour

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Abstract

Corn has six main varieties grown globally for animal feed, human consumption, and commercial/industrial purposes. Flour is an end-product of corn dry-milling. Products that are derived from corn flour often show differences in physical, chemical, and pasting properties due to corn varietal differences, milling methods, differences in flour particle sizes, and drying temperatures. The study aimed to determine the effect of different moisture contents of yellow dent corn and roller gap sizes, on the physical properties of the resulting corn flour. The possibility to use the flour in the manufacturing of animal feed and ethanol production was also considered. Yellow dent corn grain with moisture contents (MC) of 8%, 14.0%, and 18%, and roller gap sizes (GAP) of 0.1016 mm, 0.2032 mm, and 0.3048 mm were used. The Witt corrugated roller mill equipment with rollers of 1/32 inches corrugations was used to produce fine grits and flours. The particle sizes obtained were between 0.54 mm and 0.75 mm which increased with an increase in MC and GAP. Grain with 8% MC and GAP of 0.1016 mm and 0.2032 mm, and grain with 14.0% MC and GAP of 0.1016 mm can produce flour of particle sizes good for swine feed. Grain with 8% MC and GAP of 0.3048 mm and grain with 14.0.0% MC and GAP of 0.1016 mm and 0.2032 mm can produce flour of particle sizes good for ruminant feed. Grain with 18% MC and GAP of 0.1016 mm, and grain with 14.0% MC and GAP of 0.2032 mm can produce flour of particle sizes good for poultry feed. GAP of 0.1016 mm and 8% MC can produce flour of particle sizes suitable for the ethanol production industry. Flour preparation should purposely be done based on grain MC and GAP. The geometric mean diameter of particle sizes ranged from 0.54 mm-0.75 mm, and the geometric mean diameter of particle sizes increased with increasing MC and GAP. Also, grains with 8% MC had the highest loss in flour, and the higher moisture of 18% significantly affected the red color of flour.

Keywords: roller gap size, moisture content, particle size, yellow dent corn, feed, and ethanol

1. Introduction

Globally, corn follows wheat and rice as the third most important cereal crop (Adarkwah, Obeng-Ofori, Büttner, Reichmuth & Schöller, 2012). Dent corn kernel has corneous, horny endosperm in the sides and back, and has a soft central core. The floury endosperm extends into the crown of the endosperm, it gets collapsed to give a distinct indentation when dried (Johnson, 1991; PE/AI, 2016). Dent corn is the most widely grown corn in the United States Corn Belt, and most parts of the world (Boutard, 2012). Primarily, dent corn is used as animal feed, however, it is also used as a raw material in various industries and can also be used as food (Brown & Darrah, 1985).

Dry milling is used to physically change kernels into their constituent endosperms, brans, and germs (Johnson, 1991). Flour is an end-product of corn dry-milling. Food products that are derived from flour show differences in physical, chemical, and pasting properties due to differences in corn varieties (Pan, Eckhoff, Paulsen & Litchfield, 1996; Nago, Akiossoe, Matencio & Mestres, 1997; Sandhu, Singh & Malhi, 2007), methods used in milling (Nghi & Narasimha, 1994; Martinez-Flores, Martinez, Figueroa & Gonza-lez, 1998), differences in particle sizes of the flour (Bolade, Adeyemi & Ogunsua, 2009), and effect of drying temperatures on grains (Hardacre & Clark, 2006). The benefits of smaller particle sizes are to improve digestion of feed by animals, improve binding ability between particles during pelleting, improve the mixing efficiency of ingredients in a compounded feed, increase particle homogeneity, and prevent ingredient separation (Stark, 2016). Biomass feedstocks flow and compressibility depends mostly on moisture content (MC) and particle size distribution. When MC in bulk powder material is increased, the cohesion and adhesion of particles due to the formation of interparticle bonds get increased (Plinke, Leith, Boundy & Loffler, 1995; Fitzpatrick, Iqbal, Delaney, Twomey & Keogh, 2004), and flowability of the feed processing decreases (Yan & Barbosa-Canovas, 1997). An increase in particle size of ground cereals when MC is low decreases the bulk and particle densities of flours (Mani, Tabil & Sokhansanj, 2004a). The particle size of corn is affected by the production system of the grain, and feed manufacturing process (grain cleaning and grinding equipment) either by using a hammer mill (screen size, tip speed, screen opening, air systems) or roller mill (corrugations, roll differentials, and gap settings) (Stark, 2016; Koch, 1996; Waldroup, 1997). In roller milling, smaller grains may escape grinding (Douglas, Sullivan, Bond, Struwe, Baier & Robeson, 1990), and particles produced are irregularly shaped (Koch, 1996). The particles produced from a hammer mill are spherical and uniformly shaped (Reece, Lott & Deaton, 1985).

Producing smaller particle sizes increases the number of particles and surface area per unit volume which increases the accessibility to digestive enzymes (Goodbrand, Tokach & Nelssen, 2002). Handling and mixing of ingredients also become easy when particle sizes are small (Koch, 1996). Even when different grains are ground using the same mill under similar conditions, the resulting flours will have different particle sizes because it depends on the hardness of the grain samples (Nir & Ptichi, 2001; Rose, Tucker, Kettlewell & Collier, 2001; Carre, Muley, Gomez, Ouryt, Lafittee, Guillou & Signoret, 2005). Grain particle size is more important in mash feeds than when processing pellets or crumbles feeds (Nir, Hillel, Ptichi & Shefet, 1995; Svihus, Klozstad, Perez, Zimonja, Sahlstorm & Schuller, 2004a; Peron, Bastianelli, Oury, Gomez & Carre, 2005). The digestive tract of poultry (gizzard) is influenced by the particle size of the feed during its development (Nir, Shefet & Aaroni, 1994b; Cumming, 1994).

There is a need to optimize the grinding process and to develop particle size specifications for specific purposes. The grinding should give uniform particle sizes, predictable particle size distribution, and the grinding equipment should produce enough flour to meet the feed or ethanol manufacturing processes. Changing the gap sizes of roller mill equipment and using a grain of yellow dent corn with different MC could impact the physical properties of the resulting flour. For this reason, the objective of this study was to determine the effects that the different moisture contents of the yellow dent corn, and the roller gap sizes have on the physical properties of the resulting corn flours. The possibility to use the resulting flours in the feed manufacturing and ethanol production industries was also considered.

2. Materials and Methods

2.1 Experimental Design

Flour was prepared from commercial yellow dent corn samples. The corn grains with moisture contents (MC) were adjusted to 8%, 14.0%, and 18%. The roller gap sizes (GAP) used were 0.1016 mm, 0.2032 mm, and 0.3048 mm. A completely randomized factorial design was used.

2.2 Milling of Grain

A Witt Corrugated-Roller Mill was used to fractionate the whole grain into grits using a roller of corrugations of $^{1}/_{8}$ inches. The obtained grits were further milled using corrugations of $^{1}/_{32}$ inches to produce the flours. The roller mill with corrugations of $^{1}/_{32}$ inches, had its GAP adjusted to 0.1016 mm, 0.2032 mm, and 0.3048 mm to obtain different resulting flours.

2.3 Moisture Contents of Grain and Flour

The MC of grain was determined in triplicates using samples of 30 g at 103 ℃ for 72 h, following ASAE S352.2 (ASAE, 2001). The flour MC was determined using 2 g at 130^{o}C for 1 h (AACC International, 2022).

2.4 Loss in Flour and Particle Sizes of Flour

The loss in flour was determined as a percentage of the initial mass of the grit obtained from using $^{1}/_{8}$ inches corrugated roller. It is caused by the technical performance of milling machinery or incompetence operator. In determining the particle sizes of the flour, 100 g of the flour was passed through stacks of different sieve sizes by using the Tyler Ro-Tap sieve shaker (RX-29). ASAE S319.4 (2008) method was used in this analysis with US Sieve numbers between 10 - 270. The amount of flour on each sieve was used to determine the geometric mean diameter (D_{gw}) and the geometric standard deviation (S_{gw}). The calculations were performed according to the equations described in ANSI/ASAE Standard S319.4. D_{gw} and S_{gw} of flour particles were calculated using following equations;

$$D_{gw} = log^{-1}\left[\frac{\sum_{i=1}^{n}(W_i \log \bar{d}_i)}{\sum_{i=1}^{n} W_i}\right] \quad (1)$$

$$S_{gw} = log^{-1}\left[\frac{\sum_{i=1}^{n} W_i(\log \bar{d}_i - \log D_{gw})}{\sum_{i=1}^{n} W_i}\right] \quad (2)$$

Where W_i is mass on the i^{th} sieve (g), d_i is the nominal sieve aperture size of the i^{th} sieve (mm).

2.5 Color of Flour

A Minolta Chroma Meter was used to measure the colors of the flours, and measurements were taken in triplicate. The color scores of the flours were reported in terms of 3-dimensional color space based on the following rating scale: L* 100 = white, 0 = black; a* +/- = red/green; b* +/- = yellow/blue. The color values of a typical white flour, for example, were L* value +92.5 whiteness, a* value -2.4 green colors, b* value +6.9 yellow color.

2.6 Analysis of Data

The data were analyzed using ANOVA to determine if mean values were significantly different, and if so, then Tukey Kramer HSD was used (at 5%) to identify where the significant differences in means did occur.

3. Results and Discussion

3.1 Effect of the Corn Grain MC and GAP on the Geometric Mean Diameter (D_{gw}) of Flour Particles for Feed Production

The D_{gw} increased with increasing grain MC, but the difference in GAP did not affect the D_{gw}. The grain with 8% MC had the smallest D_{gw} (0.59 mm), and the D_{gw} was higher for the grain with 14.0% and 18% MC (Table 1). The effect of changing GAP on D_{gw} was only observed in the interactive effect with the grain MC. In Table 2, the interactive effect shows that irrespective of the GAP, grain with 18% MC had the highest D_{gw}. The grain with 14.0% MC had the highest D_{gw} when the GAP of 0.2032 mm and 0.3048 mm were used. The D_{gw} decreased with corresponding decreases in the MC and GAP, for example, 8% MC had the lowest D_{gw} using 0.1016 mm. The results indicate that D_{gw} was dependent on grain MC and GAP. Depending on the preferences of the feed producers, the grain of suitable MC and GAP with recommended D_{gw} are to be used.

Table 1. Individual effect of grain MC (moisture content) or roller gap on the D_{gw} (geometric mean diameter) of the resulting flour particles

Grain MC (% w.b.)	Geometric Mean Diameter, D_{gw} (mm)	Geometric Standard Deviation, S_{gw} (mm)
8.0	0.59 ± 0.05^b	1.83 ± 0.04
14.0	0.68 ± 0.06^a	1.91 ± 0.04
18.0	0.73 ± 0.02^a	1.95 ± 0.04
Roller gap size (mm)		
0.1016	0.63 ± 0.08^a	1.91 ± 0.03
0.2032	0.67 ± 0.08^a	1.91 ± 0.03
0.3048	0.71 ± 0.04^a	1.91 ± 0.03

Means ± standard deviations with different superscripts in the same column for MC or GAP are significantly different at $P < 0.05$.MC is 8%, 14.0% and 18%

Table 2. Treatment interaction effects of grain MC (moisture content) and roller gap on the D_{gw} (geometric mean diameter) and S_{gw} (geometric standard deviation) of the resulting flour particles

	Grain MC (% w.b.)	**Roller gap size (mm)**		
		0.1016	**0.2032**	**0.3048**
$\mathbf{D_{gw}}$	8.0	0.54±0.01^{e}	0.57±0.01^{de}	0.66±0.01^{bc}
	14.0	0.62±0.01^{cd}	0.71±0.01^{ab}	0.73±0.01^{a}
	18.0	0.72±0.01^{a}	0.72±0.01^{a}	0.75±0.01^{a}
$\mathbf{S_{gw}}$	8.0	1.88±0.02	1.79±0.00	1.82±0.00
	14.0	1.92±0.01	1.92±0.01	1.88±0.01
	18.0	1.99±0.01	1.94±0.01	1.93±0.01

Means ± standard deviations of the interaction with different superscripts are significantly different at $P < 0.05$. MC is 8%, 14.0.0% and 18%

The dried corn (8%) had a brittle endosperm that made the grinding very smooth than the grain with high MC (14.0% and 18 %). The soaked water in the high moisture corn (14.0% and 18 %) might have hardened the starch, endosperm, and seed coat which resulted in rough and large-sized particles. It has been reported that hard seeds produce a relatively low percentage of fine particles after grinding (Carre et al., 2005). According to Stark (Stark, 2016), a higher GAP produces large-sized particles. Rose et al. 2001 reported that endosperm hardness influenced the milling outcome of wheat, thus, harder endosperms produced larger, irregularly shaped particles while soft endosperm produced small-sized particles. Since the 8% moisture corn was dry, the endosperm was brittle and soft, and therefore smoother particles were produced. Comparatively, the endosperms of the 14.0% and 18% MC grain were hard and resilient to break which resulted in large-sized particles.

The advantages of using the 8% MC grain are observable in the digestive system of livestock and industrial processing of feed which requires small-sized particles. Small-sized particles have the advantage of an increased number of particles and surface area per unit volume, and therefore accessibility to digestive enzymes also increases (Goodbrand et al., 2002). Small-sized particles also make feed formulation processing less complex (Koch, 1996; Mathew, Hoseney & Faubion, 1999; Carvalho & Ascheri, 1999). Preparing different types of feeds for livestock (ruminants), swine, and poultry require particular-sized particles. The benefits of particle size reduction are to improve feed digestion, improve binding ability between particles, improve the mixing efficiency of ingredients in a compounded feed, increase particle homogeneity, and prevent ingredient separation (Stark, 2016; Ying & Allen, 1998; Stark, Jones, Goodband & Kalivoda, 2010). Using flour prepared from the grain with 14.0% MC and the smallest GAP (0.1016 mm) can be advantageous in the feed industry because the flour had a smaller D_{gw} (0.62 mm). This is because flours with high MC and small-sized particles are reported to have many advantages. Reports indicate that finely ground flour with high MC increased the rate and level of rumen fermentation and digestion (Ying & Allen, 1998; Lykos & Varga, 1995; Knowlton, Glenn & Erdman, 1998), and digestion in swine (Steinhart, Tokach & DeRouchey, 2012).

However, there should be a limit to particle size used, because small-sized particles could increase the risk of rumen acidosis in cattle, reduce the dry matter intake and rumen fermentation, and milk characteristics (Ying & Allen, 1998). MC and particle size distribution contribute significantly to the flow and compressibility properties of biomass feedstocks (Fitzpatrick et al., 2004; Yan & Barbosa-Canovas, 1997). Grain with low MC (8%) and a smaller GAP (0.1016 mm and 0.2032 mm) can increase dust problems, increase feed processing cost, and also increase the incidence of gastric ulcers in swine (Steinhart, Tokach & DeRouchey, 2012). The digestive tract of poultry (gizzard) is influenced by feed particle size during development (Nir & Ptichi, 2001; Nir, Shefet & Aaroni, 1994b; Cumming, 1994). Generally, broilers require diets having relatively large particle sizes. However, small-sized particles are important when preparing feed pellets for poultry (Amerah, Ravindran, Lentle & Thomas, 2007). Different animals have different feed particle size requirements. Swine's feed efficiency improves using small-sized particles (0.54 mm and 0.57 mm D_{gw}), and poultry's feed efficient increases using large-sized particles (0.71-0.75 mm D_{gw}) (Stark, 2016; Nir & Ptichi, 2001; Stark et al., 2010; Steinhart, Tokach & DeRouchey, 2012). Therefore feed producers should be aware of the grain MC and GAP used to obtain appropriate particle size formation.

3.2 Effect of Grain MC and GAP on Geometric Mean Diameter (D_{gw}) of Particles of Flour for Ethanol Production

Another industrial usage of yellow dent corn is in the ethanol production sector. The particle size in ethanol production is important as it directly relates to the amount of starch released. In this study, the D_{gw} was in the range of 0.54 mm to 0.75 mm (Table 1). The grain with 8% MC generally had the smallest D_{gw} than the grain with higher MC, but the different GAP did not change the D_{gw}. The effect of GAP was observed only in the interactive effect (Table 2). Lamsal et al. (2011) reported D_{gw} in the range of 1.18 mm and 1.27 mm using the GAP between 0.2032 mm and 0.508 mm, and corn grain with 15% MC. The results of this study differ from that of Lamsal et al. 2011 and could be due to varietal differences in the corn grain used. Rausch et al. 2005 reported in their survey of nine dry-grind ethanol plants in the upper Midwest United States, that D_{gw} of ground corn was 0.94 mm. This value was above the D_{gw} obtained in our current study. However, a recent study by Liu, 2009 showed the D_{gw} of ground corn particles from six dry-grind ethanol plants in Iowa and South Dakota to range from 0.43 mm to 0.52 mm. Therefore, it would be appropriate to use grain with 8% MC and GAP 0.1016 mm and 0.2032 mm to produce flour of suitable size for ethanol production.

Using grain with 14.0% and 18% MC produced D_{gw} above the average size (0.48 mm) used in most ethanol plants even at the lowest GAP used (0.1016 mm). Reports have also indicated that small-sized particles increase ethanol productivity (Kelsall & Lyons, 2003; Naidu, Singh, Johnston, Rausch & Tumbleson, 2007; Yeh, Huang & Chen, 2010; Lamsal, Wang & Johnson, 2011; Khullara, Dien, Rausch, Tumblesona & Singh, 2013). The finer the flour, the higher the enzyme kinetics and quantity of sugars produced, because of the increased surface area of the small-sized particles available to enzymes (Kelsall & Lyons, 2003). According to Khullar et al. 2013, using a 0.08 mm sieve screen produced a high percentage of ethanol conversion than using a 2 mm and 6 mm. Small-sized particles were reported to cause several problems during the ethanol production including higher power requirements and harder separation process in the decanter and thin stillage evaporator. Considering the short tempering process time, the grain with 8% MC was appropriate. Hurburgh et al. 2014 reported grain MC to be theoretically between 8% and 14.0%. The smallest GAP (0.1016 mm) can best be selected because the D_{gw} obtained using the grain with 8% MC could have high soluble solid content in the thin stillage of the ethanol fermentation. However, for grain with the same MC, changing GAP may not have any statistically significant effect on D_{gw} of the flour (Table 1) and probably ethanol production. This observation supports the findings of Lamsal et al. 2011; different GAP tested for a grain of the same MC did not give any significant difference in the value of the ethanol produced.

3.3 Effect of Grain MC and GAP on Loss in the Flour, and the Flour MC

Table 3. Individual effect of grain MC (moisture content) or roller gap on the losses in flour, and resulting flour MC

Grain MC (% w.b.)	**Loss in flour (%)**	**Flour MC (% w.b.)**
8.0	2.07 ± 0.76^{a}	8.75 ± 1.607^{b}
14.0.0	0.67 ± 0.27^{b}	$14.0.33 \pm 1.81^{ab}$
18.0	1.00 ± 0.80^{b}	22.0 ± 10.50^{a}
Roller gap size (mm)		
0.1016	1.37 ± 0.73	$14.0.25 \pm 6.01$
0.2032	1.10 ± 1.06	16.58 ± 9.84

Means ± standard deviations with different superscripts in the same column are significantly different at $P < 0.05$. MC is 8%, 14.0.0% and 18%

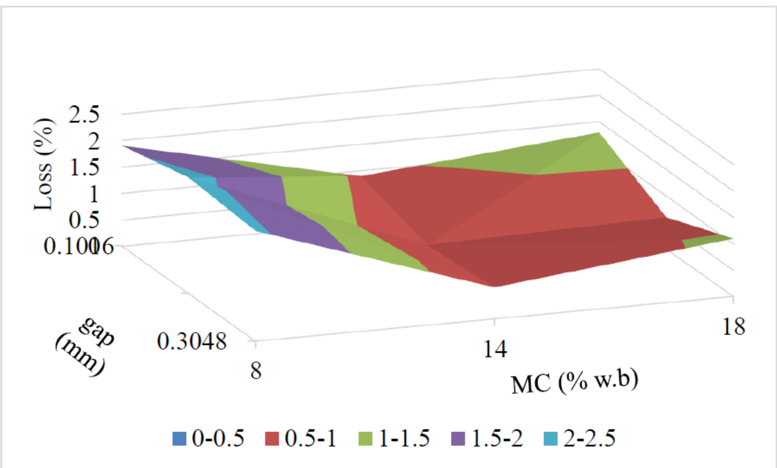

Figure 1. The impact of grain moisture content (% w.b.) and roller gap (mm) on losses in flour

In Table 3, the varied GAP did not affect the flour MC and loss in flour quantity, however, grain MC resulted in a loss in quantity of the flour. The quantity of the flour lost significantly depended on grain MC. Due to this, the highest loss was observed in the grain with the lowest MC (8%) but was minimal in the grain with 14.0% and 18% MC. The dried endosperm of grain when ground easily shatters to disperse clouds of smooth powdery flour, and therefore most of the resulting flour is escaped and was counted as a loss. This might have been the reason for the highest flour loss in grain with 8% MC compared to moist grain which prevents the shattering and dispersing of the endosperms. This result was illustrated in Figure 1.

The flour MC depended on the grain MC. The grain with the 18% MC produced flour with a corresponding high MC of 22%. Although high MC can result in deterioration, but it also could increase cohesion and adhesion of particles by forming interparticle bonds in bulk powdered materials (Plinke et al., 1995; Fitzpatrick et al., 2004), and flowability is decreased (Yan & Barbosa-Canovas, 1997). Hence, to minimize the loss in flour quantity, the MC of grain should be less than 8%. Additionally, the high flour MC could cause deterioration and reduces the feed's shelf-life.

*3.4 Effect of Grain MC, GAP, and their Interaction (MC*GAP) on the Flour Color*

The type and form of animal feed preparation correlate to some flour properties including flour MC, particle size, color, etc. Color is an important factor in feed processing and can make the end product acceptable or unacceptable to the feed buyer. In Table 4, GAP, and grain MC and GAP interaction did not have any effect on the color of the flour (L*, a*, and b*). But grain MC only significantly affected a* (red) color of the flour. The only significant effect on the color of the flour (a*) was the grain with 18% MC. Thus, a* (red) color was significantly the same for the flours from the grain with 8% and 14.0% MC (Table 5). The red color of corn lies in the hull (HAES, 1904). As grain absorbs water the red pigment becomes very noticeable. Hence, the flour from the grain with 18% MC had the highest red color compared to the flours from the 8% and 14.0% MC. Thus, the compound for the red coloration reacted with the high amount of water, making it very noticeable. The result shows that irrespective of the MC and GAP, the flours had similar white (L*) and yellow (b*) colors. White color is a property that correlates best with processing; however, the increased MC and GAP did not affect the white color of the flour. Since the MC and GAP did not affect the white (L*) color this is a better indication for feed or food preparation. Figure 2 (a – b) illustrates the effect of grain moisture content and roller gap on flour color.

Table 4. Treatment interaction effects of grain MC (moisture content), roller gap, and treatment interaction effects of the MC*gap interaction on the resulting flour color (p-values)

	L*	**a***	**b***
Grain MC	0.42	0.03*	0.46
Roller gap size (gap)	0.80	0.30	0.70
MC*gap interaction	0.47	0.99	0.56

*Significant effect at $P < 0.05$. MC is 8%, 14.0.0% and 18%

Table 5. Individual effect of grain MC (moisture content) on the resulting flour color

Grain MC (% w.b.)	**L***	**a***	**b***
8.0	85.85 ±6.02	3.49 ±0.76^{b}	30.03 ±2.50
14.0.0	94.75 ±11.93	3.91 ±0.94^{b}	33.38 ±4.97
18.0	91.62 ±12.85	6.00 ±1.90^{a}	30.69 ±5.20

Means ± standard deviations in the same column with different superscript are significantly different at $P < 0.05$.

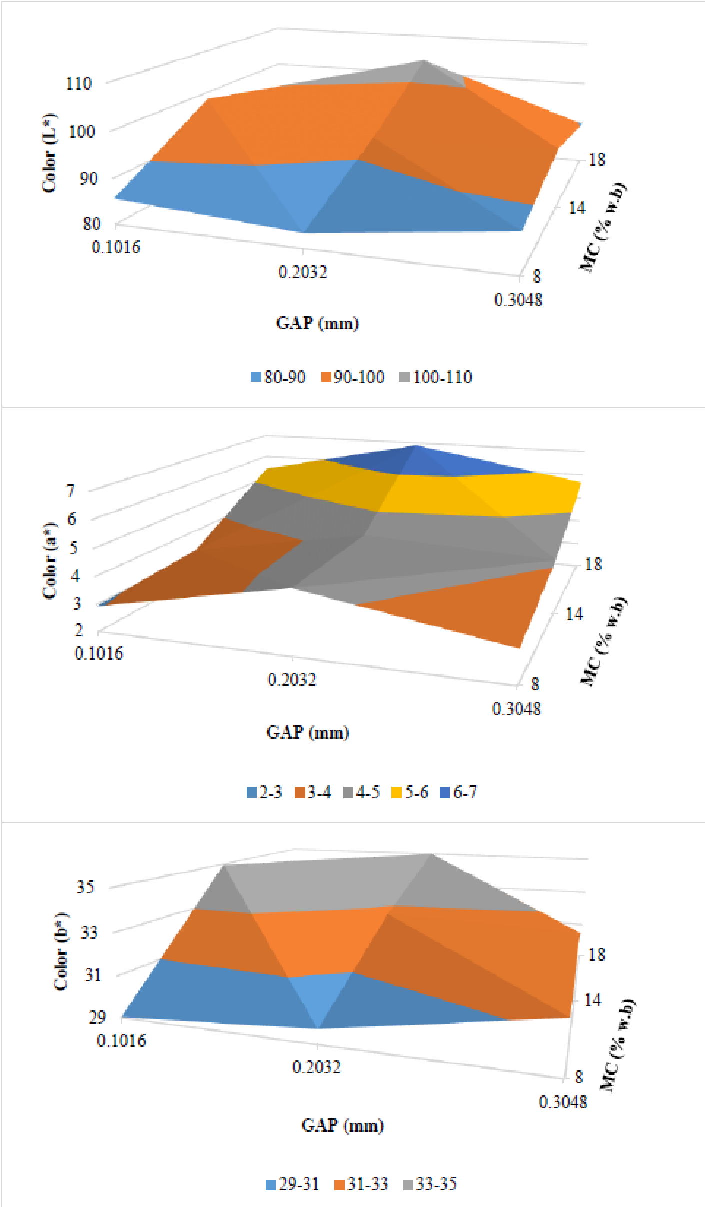

Figure 2 (a) (b) (c). The impact of grain moisture content (% w.b.) and roller gap size (mm) on flour color (L*, a*, b*).

4. Conclusions

The obtained particle sizes ranged from 0.54 mm to 0.75 mm. There was a corresponding increase in particle sizes as grain MC and GAP increased. In preparing swine feed which generally requires particle size of flour of around 0.5 mm, using grain with 8% MC and GAP of 0.1016 mm and 0.2032 mm or grain with 14.0% MC and GAP of 0.1016 mm can produce flour of the required particle size. This is to improve feed efficiency and reduce daily grain intake. In preparing ruminants' feed which generally requires flour particle size of around 0.7 mm, using grain with 8% MC and GAP of 0.3048 mm, or grain with 14.0% MC and GAP of 0.1016 mm and 0.2032 mm can produce flour of the required particle size. Reportedly, this improves milk production, digestion, and reduces gastric ulcers. For poultry feed of particle size which is generally above 0.7 mm, using grain with 18% MC and GAP of 0.1016 mm or grain with 14.0% MC and GAP of 0.2032 mm can produce flour of the required particle size. These particle sizes have been reported to enhance egg production, digestion, and broiler developments. Using GAP of 0.1016 mm and grain with 8% MC can produce flour of particle sizes suitable for the ethanol production industry. The white and yellow colors of the resulting flour were not affected by the different levels of MC and GAP. The effect of the grain MC on the flour color was only significant for the red color in the 18% MC grain. Per the purpose of the flour preparation (feed or ethanol production), the grain MC and GAP can be carefully selected to obtain desirable particle sizes.

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