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Effect of Flow Agent Addition on the Physical Properties of DDG with Varying Moisture Content Soluble Percentages

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Abstract. *Distillers Dried Grains with Solubles (DDGS) is widely recognized as a highly nutritious animal feed ingredient. With the exponential growth of the fuel ethanol industry in the past several years, significant quantities of distillers' grains are now being produced. To effectively utilize these feeds in the domestic market, however, these coproduct streams are increasingly being transported greater distances, and must be stored in various structures until final use. Unfortunately, DDGS flow is often problematic, as it frequently becomes restricted by caking and bridging during storage and transport. This issue may arise from a number of factors, including storage moisture, temperature, relative humidity, particle size, time, or temperature variations. The objective of this study is to examine the effect of various moisture content levels (10, 15, 20, 25, 30% db) and calcium carbonate levels (0, 1 and 2% wb) on the resulting flow properties (Carr Indices) of DDGS with varying soluble percentages (10, 15, 20 and 25% db). The results showed that there are some flow issues in DDGS with increased soluble and moisture content levels. Flow agent (CaCO_3) addition did not have a significant effect in improving the flow properties of DDGS with various soluble and moisture content levels. This may be due to no surface affinity between DDGS and flow agent particles or less inclusion rate of flow agent.*

Keywords. DDGS, flowability, Solubles, Carr Indices, CaCO_3 , Flow agent.

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1 Introduction

Corn is the predominant grain used for ethanol production in dry mill ethanol operation, as it has more starch compared to other feedstock grains. Distillers' dried grains (DDG), Condensed distillers' solubles (CDS), also called as syrup, or a combination product, distillers' dried grains with solubles (DDGS), are the by products produced from ethanol dry grind processing. In most plants, the solubles are added back to the grain or cake. CDS is a brown, free flowing to semi-solid liquid and because of its nutritive composition and high palatability, there is a high interest in mixing it with low quality roughages to serve as a feed to many livestock rations. It is an excellent source of vitamins, is low in fiber, relatively high in fat, and yields a digestible energy value approximately 91% of that of raw corn (Buchheit, 2002; Cruz et al., 2005). Distillers' dried grain with solubles (DDGS) has been renowned as a valuable source of energy, protein, water soluble vitamins and minerals for animal feeds. Distillers' grains contain 80 to 90% (d.b.) dry matter, 25 to 35% (d.b) crude protein and 8 to 10% (d.b) fat (Tjardes and Wright, 2002). With the high demand of ethanol, there was a tremendous growth of the U.S. ethanol industry in the past decade. Significant quantities of distiller's grains are now being produced. In 2006-2007, DDG production is forecasted to be 13.0 million tons due to raising demand for fuel grade ethanol (AAFC Bulletin, 2006). It is important to increase the use of distillers' grains in domestic market. DDGS is usually transported through rail carts. During transportation, DDGS is subjected to different temperature and humidity levels and are stored in bins and silos until use; sometimes this may be a relatively long time. The storability and resulting flowability of DDGS is currently becoming very problematic (AURI and MCGA, 2005).

Furthermore, marketing of distillers' grain products is hampered by inconsistencies in physical properties, both within a single plant over time, as well as between plants. Quantification of physical properties is important, because DDGS storage and flow behavior depends on the physical and chemical properties of DDGS, as well as environmental variables. Some of the more obvious ones which affect flowability are particle size, cohesion, particle interaction, ability to recover from compaction, temperature, relative humidity, vibration during transportation. The flowability of DDGS and their flow behavior under various pressures, temperatures and humidity are important in handling operations such as storage in silos or hoppers, transportation through rail carts and packaging.

The handling, storage, and flow of any particulate (like DDGS) materials is important in industries associated with agricultural, food, chemical, ceramic, pharmaceutical and metallurgical bulk solids and powder processing. Flow is defined as the relative movement of a bulk of particles among neighboring particles, or along a container wall surface (Peleg, 1977). Flow characteristics are of immense significance in bulk material handling and processing, since the ease of conveying, blending, and packaging depends on them. Reliable flow optimizes designs and maximizes profits. To ensure steady and reliable flow, it is crucial to accurately characterize the flow behavior of these materials (Kamath et al, 1994).

Caking and stickiness are common problems that almost every industry dealing with granular solids and powders encounters. It is very important that the bulk solids do not cake partially or totally even after a long storage time. If it cakes, then machinery, manpower and time are needed to break these unwanted agglomerates, adding costs to the customer. Caking is defined as when two or more macroparticles, each capable of independent translational modes, contact and interact to form a conglomerate in which the particles are incapable of independent translations (Barbosa & Yan, 2003). Flow conditioners and anticaking agents, also called glidants, antiagglomerants, lubricants, dispersion agents, and free flowing agents, are commonly identified as additives that will assist a powder in maintaining a steady flow and/or

increase its flow rate. Inter and intra-particle forces, particle size, and shape, as well as moisture and fat contents, are the sources of most flow problems. Flow conditioners are usually made from chemically inert substances, and are often effective at concentrations up to 2%. Most are insoluble in water, but many of them can adsorb significant quantities of moisture as a result of their very large surface areas.

Many research studies have examined the effect of flow conditioners on flow properties of granular solids and powders in the past few decades. A significant caking inhibition was found when surfactants such as lauryl amine and sodium dodecyl sulfonate were added to ammonium perchlorate (Chen & Chou, 1993). Onwulata et al. (1996) studied the effect of three flow conditioners (calcium stearate, aluminum silicate, and silica) at three levels of concentration (0, 1, and 2%) on the bulk and flow properties of sucrose, lactose, and modified corn starch as well as butter oil powders encapsulated with the same materials. They found that silica and silicate as flow conditioners were effective in improving the flowability of un-encapsulated powders as well as lactose encapsulated butter oil powders, whereas the stearate flow conditioner resulted in flow retardation of all powders. Two dispersion agents, Cab-o-Sil and Zeofree 80, have been found to have a significant effect on the flowability of spray dried soymilk (Perez & Flores, 1997).

To be effective, the conditioning agent must be finer than the material to be conditioned. The finer the particle size of the conditioner, the less severe is the caking of the original material (Irani et al, 1959). The conditioner's particles must stick to the host powder particles; thereby producing a smoother and less frictional surface by filling the void spaces (Peleg & Hollenbach, 1984). Flow properties of conditioned powders are strongly influenced by the kind of surface interaction between the host powder and the conditioner particles (Hollenbach et al, 1983). For example, dolomitic limestone had an arching dimension of 3.2 ft in a mass flow bin, whereas with a fractional addition of flow additive showed a zero arching dimension. The flow aid reduced the permeability of limestone by 100 times and manifestly smoothed the surface of the particles thereby prevented interlocking (Johanson 1978). Addition of tricalcium phosphate, magnesium carbonate, and Santocel®C up to 4% to barely malt flour, bread flour, and cake flour improved their flow properties (Irani & Callis, 1960). Addition of magnesium oxide of concentration 1% or less (Craik, 1958) and tricalcium phosphate (Sjollema, 1963) was found to be effective for improving the flow properties of maize starch and milk powder respectively. Flow properties of maize starch, sucrose and sodium chloride were found to be increased on the addition of magnesium oxide. This improvement was due to the reduction of adhesion between the particles (Craik & Miller, 1958).

Above a certain inclusion rate, however, the conditioner can retard the overall flow of the material (Hollenbach et al, 1982; Nash et al, 1965; Irani et al, 1959). If the surface affinity between the host powder and conditioner is strong, then large effects will be present in the bulk density and compressibility at inclusion concentrations of 0.1 to 0.5%. When there is a little affinity, the effects become noticeable only at 1 to 2% concentration (Hollenbach et al, 1983). Danish and Parrott (1971) investigated the effect of size and concentration of lubricants (hydrogenated castor oil, glycerol monostearate, polyethylene glycol 4000, and stearic acid) on the flow rate of sodium chloride and lactose granulations. With both sodium chloride and lactose granulation, the maximum flow rate increased when the lubricant's concentration was 1% or less and had a diameter of 0.0213 cm. Peleg and Mannheim (1973) found that two conditioners, calcium stearate and aluminum silicate, inhibited the caking tendency and improved the flowability of powdered sucrose. It seemed that calcium stearate gave a better effect, however. It was observed that an increase in the amount of tricalcium phosphate, maltodextrin, and glycerol monostearate decrease the degree of caking of dried mango powder (Jaya & Das, 2004). From many research studies, it has been found that the host powder and

the conditioner particles should have a surface affinity. Hollenbach et al. (1983) found that calcium stearate and silicon oxide had no effect on improving the flowability of soy protein powder. This was due to the poor affinity between the conditioner and the host powder. If there is no attraction between the particles, then the conditioner particles themselves will segregate together, and instead of reducing overall cohesiveness, will fill the interparticle voids (Peleg, 1983).

Previously the authors found that increased addition of solubles and moisture affected DDGS flow properties (Ganesan et al., 2005a, 2005b). Addition of flow conditioning agent might improve the flow properties of DDGS. Hence the objective of this study was to examine the effects of five moisture content levels and three flow agent (CaCO_3) levels on the physical properties of DDGS with four varying soluble percentages.

2 Materials and Methods

2.1 Moisture

Distillers' dried grains (DDG) and syrup were procured from Dakota Ethanol Plant (Wentworth, SD), and were stored in sealed plastic buckets (the DDG at room temperature and the CDS at $4^\circ\text{C} \pm 1^\circ\text{C}$) until needed. The moisture content of DDG and syrup was determined using air oven method (AACC 44-19). Triplicates were done for each sample.

2.2 Preparation of DDGS with Various Soluble Percentages, Moisture Contents and Flow Agent Levels

DDGS with the specific soluble percentage (10, 15, 20 & 25 %db) was prepared first, and then dried, using hot air oven at 100°C , to the required moisture content levels (10, 15, 20, 25 & 30 %db). In-depth details are found in Ganesan et al 2005a and 2005b. Around 9 kg of sample was prepared for each combination of soluble and moisture content. Then it was divided into 3 batches of approximately 3 kg and 0, 1 and 2 percent of calcium carbonate (CaCO_3) were added to each batch. After that it was mixed for 10 min using laboratory rotary drum mixer. The prepared samples were sealed in freezer bags and stored at $4^\circ\pm 1^\circ\text{C}$ until its use to prevent moisture loss.

2.3 Physical Properties

The physical properties measured were color and particle size. The color values, L^* (brightness), a^* (redness), b^* (bluish yellow), were measured using Minolta chromameter (Model CM 2500d, Minolta, Japan). Particle size distribution was measured by sieve analysis method (ASAE S319.3) using Tyler sieve analyzer (Model RX-29). Three replicates were done on each sample.

2.4 Flow Property Measurement by Carr Indices Test

Carr (1965) described a number of standard procedures that permit the evaluation of flow characteristics of any granular materials. These procedures also endow information that is crucial to determine and understand the possible flow problems of various granular materials. There are two types of material flow; they are free flow and floodable flow. A free flowing material tends to flow in a steady and consistent manner, as individual particles, even through a fine orifice. A non flowing material will tend to flow "en masse" or as agglomerated particles. Floodable flow is an unstable, liquid like flow. It can be discontinuous, gushing, uncontrollable and spattering. It can be caused by the fluidization of a mass of particles by air. Hosokawa powder characteristic Tester (Model PTR, Hosokawa Micron Powder systems, NJ) was used for measuring the flow properties of DDG with various soluble percentages, moisture content levels and flow agent levels, which follows the procedure described by Carr (ASTM D6393). Powder

tester was used to measure the flowability indices and floodability indices of DDGS. Flowability indices are the sum of the indices of angle of repose (AoR), compressibility, angle of spatula (AoS), and uniformity. Floodability indices are the sum indices of angle of fall (AoF), angle of difference (AoD), dispersibility and flowability index.

2.4.1 Flowability Index

The evaluation of the flow characteristics of a dry material will involve the use of four properties that can be readily measured:

2.4.1.1 Angle of Repose (AoR)

Angle of repose is defined as the angle between the horizontal and the slope of a heap of granular material dropped from some elevation. Angle of repose corresponds qualitatively to the flow properties of that material, and is a direct indication of the potential flowability.

2.4.1.2 Compressibility

The compressibility percentage of a material can be computed by the following equation:

$$100 (P-A) / P = \% \text{ Compressibility}$$

where: P is packed bulk density (kg/cm^3); A is aerated bulk density (kg/cm^3). The greater the compressibility of a bulk solid, the less flowable it is. Compressibility can be used to indirectly assess properties such as uniformity in size and shape, deformability, surface area, cohesion and moisture content of the material.

2.4.1.3 Angle of Spatula (AoS)

This is an easily determined property which gives a relative angle of internal friction, or angle of rupture, for a dry material. A highly flowable material will have an obtuse angle of spatula. It is an indirect measurement of cohesion, surface area, size, shape, uniformity, fluidity, deformability and porosity of the material.

2.4.1.4 Uniformity

The coefficient of uniformity is used with granular materials on which an effective surface cohesion cannot be measured. It is a ratio obtained between the width of sieve opening that will pass 60% of the sample and width of sieve opening that will pass only 10% of the sample. The more uniform mass of particles is in both shape and size, the more flowable it is likely to be. Uniformity coefficient is an indirect measurement of size, shape and compressibility of the material.

Individual measuring values above are assigned an index value. Maximum index value=100, indicates the material flowability is very good.

2.4.2 Floodability Index

The evaluation of the potential floodability of a material involves the use of the following properties of dry materials:

2.4.2.1 Flowability Index

Flowability index also partly indicates the floodability of a bulk material. Higher the flowability index, the higher is the risk that the material floods through.

2.4.2.2 Angle of Fall (AoF)

Angle of fall is the new angle of repose formed when impaction energy was given. The more floodable the material is the lower its angle of fall and its angle of repose will be. The angle of fall is an indirect measure of fluidity, shape, size, uniformity and cohesion.

2.4.2.3 Angle of Difference (AoD)

This is the difference between the angle of repose and angle of fall. Larger the angle of difference, larger the material's potential for flooding and fluidizing. It is an indirect measure of fluidity, surface area and cohesion.

2.4.2.4 Dispersibility

Dispersibility and floodability are interrelated. The higher the dispersibility index of a material, the dustier and the more floodable it can be.

The sum of flowability index and other individual measurements gives the bulk material floodability index. Maximum index value =100: floodability is very high.

2.5 Statistical Analysis

DDGS with four soluble levels (10, 15, 20 & 25%db), five moisture content levels (10, 15, 20, 25 & 30%db) and three flow agent levels (0, 1 and 2%wb) were prepared, which resulted in a total of 60 treatment combinations (a $4 \times 5 \times 3$ factorial design) for the study, which was implemented using a Completely Randomized Design. Each treatment was done in triplicates for all the physical property analysis, which resulted in a total of 180 experimental runs. Statistical analyses on the collected data were done using Proc GLM analysis of SAS software (SAS Institute, Cary, NC, USA) with a Type I error rate (α) of 0.05 to test for significant differences between the treatments.

3 Results and Discussion

3.1 Color

Results obtained for the main effect of soluble, moisture and flow agent levels on the color of DDGS is provided in Table 1. Statistical analysis on all the resulted data proved that differences between treatments did exist. Table 1 shows that the brightness (L^*) of DDGS, decreased from 51.77 to 34.82 and the redness (a^*) value increased from 13.89 to 16.47 with an increase in soluble percentage from 10 % db to 25% db. The differences between the color values of DDGS with various soluble percentages were statistically significant. This was due to the addition of more CDS, which is of brown color, to DDGS. The bluish yellow (b^*) value didn't show any constant increasing or decreasing trend with increase in soluble percentage. But it still showed a statistically significant difference between the treatments. Increase in moisture content also observed to be significantly influencing color values of DDGS but there found no proper trend. Increase in flow agent levels (CaCO_3) increased the brightness (L^*) of DDGS from 40.71 to 46.94 and decreased the redness (a^*) values from 16.69 to 14.16 significantly. But the bluish yellow (b^*) values of DDGS did not show any clear trend as it was observed for L^* and a^* values.

3.2 Flow Property Analysis

The main effects due to soluble level, moisture content, and flow agent addition on the resulting Carr Indices are provided in Table 1.

3.2.1 Angle of Repose

Carr (1965) categorized the materials flowability from "very good" to "very bad". Materials with angle of repose $< 40^\circ$ would not have any flow problem and greater than 45° would not flow easily. Angle of repose of DDGS was not significantly affected by low levels of solubles. Only 25% db solubles had a significant effect on angle of repose of DDGS. Moisture content and flow agent did not have a noticeable effect on DDGS angle of repose. The mean values of angle of repose ranged from 45° to 46.1° with varying soluble percentages, 45.15° to 46.01° with varying moisture content levels and 45.15° to 45.66° with varying flow agent levels, which falls into the flowability category of "normal" to "not good".

3.2.2 Compressibility

Compressibility of DDGS was significantly affected by soluble and moisture content, but we did not observe any clear trend. There found to be no significant effect of flow agent (CaCO_3) levels on the DDGS compressibility. Materials with compressibility value of $< 25\%$ are categorized as good flowable materials and $>25\%$ are categorized as less flowable materials. In our study, the mean compressibility values ranged from 2.59% to 3.10% with varying soluble percentages, 2.18% to 4.16% with varying moisture content and 2.69% to 2.87% with varying flow agent levels. Degree of flowability of materials with $<5\%$ compressibility are ranked as very good.

3.2.3 Angle of Spatula

Materials with an angle of spatula $<60^\circ$ are ranked as good flowable materials and $>60^\circ$ are ranked as bad flowable materials. There was a significant difference in the DDGS angle of spatula values between 10% db solubles and 25% db solubles and 10% db moisture content and 30% db moisture content. There found to be no significant effect of flow agent (CaCO_3) levels on the DDGS angle of spatula. The mean values of angle of spatula ranged from 58.72° to 60.80° with varying soluble percentages, 59.45° to 60.98° with varying moisture content levels and 59.35° to 60.29° with varying flow agent levels, which falls into the flowability category of "normal" to "not good".

3.2.4 Uniformity

It has been categorized that the materials with uniformity <17 as good flowable materials and greater than 17 as less flowable materials. Uniformity of DDGS was significantly affected by soluble and moisture content, but we did not observe any clear trend. There found to be no significant effect of flow agent (CaCO_3) levels on the DDGS uniformity values. In our experiments, the mean uniformity values ranged from 1.70 to 2.53 for soluble percentages, 2.03 to 2.23 for moisture content and 2.07 to 2.18 for flow agent levels. Degree of flowability of materials with uniformity less than 6 are ranked as very good.

3.2.5 Flowability Index

Flowability index is the sum of the indices of all the above four properties. Flowability index of 100 stands for a material with very high flowability. There was observed a significant difference between the flow indices of 15% db solubles and 20% db solubles. Also the moisture

content levels had a significant effect on the flow index of DDGS. But there was no statistically significant effect of flow agent on the flow indices of DDGS. The mean flow indices values ranged from 76.49 to 76.61 for soluble percentages, 76.02 to 77.67 for moisture content levels and 76.62 to 77.10 for flow agent levels. This shows that DDGS has good flowability and sometimes vibration is required for bridge breaking measures.

3.2.6 Angle of Fall

Materials with angle of fall less than 39° are categorized as highly floodable and greater than 40° as less floodable. Angle of fall of DDGS was significantly affected by 15% db solubles compared to other soluble percentages. Moisture content agent did not have a noticeable effect on DDGS angle of fall. Flow agent levels (1% wb and 2% wb) had a significant effect on DDGS angle of fall over 0% wb flow agent level. The mean values of angle of fall ranged from 37.51° to 40.39° for soluble percentages, 38.92° to 39.91° for moisture content levels and 38.51° to 39.77° for flow agent levels, which falls into the floodability category of “fairly high”.

3.2.7 Angle of Difference

Materials with angle of difference less than 16° are categorized as less floodable and greater than 17° as highly floodable. Angle of difference of DDGS was significantly affected by 15% db soluble percentage. There was a significant difference in angle of difference between 20 and 30% db moisture content levels. Flow agent also had a significant effect on angle of difference values. Angle of difference values decreased from 6.65° to 5.71° with increase in flow agent levels. In our study, the mean angle of difference values ranged from 5.48° to 7.50° with varying soluble percentages, 5.28° to 6.50° with varying moisture content and 5.71° to 6.65° with varying flow agent levels which falls into the floodability category of “may flush” to “would not flush”.

3.2.8 Dispersibility

It has been categorized that the materials with dispersibility less than 20 as less floodable materials and greater than 20 as highly floodable materials. Dispersibility of DDGS was significantly affected by both soluble and moisture content, but there found no trends. Dispersibility value was decreased from 10.56 to 8.98 with increase in flow agent levels. In our study, the mean dispersibility values ranged from 7.90 to 11.43 (soluble percentages), 7.50 to 13.49 (moisture content) and 8.98 to 10.56 (flow agent levels), which falls into the floodability category of “tends to flush” to “may flush”.

3.2.9 Floodability Index

It is the sum of the flowability index, angle of fall index, angle of difference index and dispersibility index. Material with floodability index greater than 60 would easily flood and less than 60 would not. Floodability index had a significant effect of soluble, moisture and flow agent levels. Floodability index decreased from 56.25 to 53.97 with increase in flow agent levels. In our study, the mean flood indices ranged from 54.15 to 56.00 for soluble percentages, 53.74 to 57.59 for moisture content and 53.97 to 56.25 for flow agent levels, which fall into the floodability category of “tends to flush”. This shows that the DDGS sometimes require rotary seal for flush prevention and is not highly floodable to cause any catastrophe.

It was expected that the addition of calcium carbonate as flow agent would noticeably improve the flow properties of DDGS. But the flow agent failed to improve the flow properties of DDGS significantly. This may be due to no surface affinity between calcium carbonate and DDGS, or perhaps the inclusion rate was not enough to improve the flow properties of DDGS. It

is also possible that moisture and solubles at higher levels can alter the DDGS surface properties to such an extent that the adherence pattern may also be modified. Surface affinity between the DDGS and calcium carbonate particles is a crucial factor in regulating the flow characteristics of conditioned DDGS. Examining the conditioned DDGS with scanning electron microscopy might reveal whether surface affinity exists between DDGS and calcium carbonate or not.

4. Conclusions

This study has shown that the amount of soluble content, moisture content and flow agent had a significant effect on the DDGS color. The brightness (L^*) of DDGS decreased and redness (a^*) values of DDGS increased with increase in soluble percentage. With addition of flow agent, DDGS brightness values increased and the redness values decreased. Increase in soluble percentage and moisture content levels had a noticeable effect on Carr Indices, including angle of repose, compressibility, angle of spatula, uniformity, angle of fall, angle of difference, dispersibility, flow index and flood index. These results have shown that DDGS is not a highly flowable or floodable material. Flow agent levels did not show any significant improvement in the flow properties of DDGS, however.

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Table 1: Effect of soluble content, moisture content and flow agent levels on the physical and flow properties of DDGS

Physical and Flow Properties	Parameters											
	Soluble Levels(%db)				Moisture Levels (%db)					Flow Agent Levels(%wb)		
	10	15	20	25	10	15	20	25	30	0	1	2
AoR (deg)	45.14 ^b	45.00 ^b	45.46 ^{ab}	46.10 ^a	45.20 ^a	45.32 ^a	45.15 ^a	46.01 ^a	45.45 ^a	45.15 ^a	45.66 ^a	45.46 ^a
ABD (g/cc)	0.51 ^b	0.58 ^a	0.58 ^a	0.58 ^a	0.56 ^{bc}	0.57 ^{ab}	0.57 ^{ab}	0.56 ^{cd}	0.55 ^d	0.57 ^a	0.56 ^b	0.57 ^a
PBD (g/cc)	0.53 ^b	0.60 ^a	0.59 ^a	0.60 ^a	0.58 ^b	0.58 ^{ab}	0.59 ^a	0.57 ^b	0.57 ^b	0.58 ^a	0.57 ^b	0.58 ^a
Comp (%)	2.59 ^b	2.80 ^{ab}	2.61 ^b	3.10 ^a	2.61 ^{bc}	2.22 ^{bc}	2.18 ^c	2.69 ^b	4.16 ^a	2.69 ^a	2.77 ^a	2.87 ^a
AoS (deg)	60.80 ^a	59.75 ^{ab}	60.47 ^a	58.72 ^b	59.45 ^b	59.77 ^{ab}	59.74 ^{ab}	59.73 ^{ab}	60.98 ^a	59.35 ^a	60.29 ^a	60.16 ^a
Uniformity	2.34 ^b	2.53 ^a	1.98 ^c	1.70 ^d	2.13 ^{abc}	2.23 ^a	2.12 ^{bc}	2.03 ^c	2.18 ^{ab}	2.07 ^a	2.18 ^{ab}	2.17 ^a
AoF (deg)	39.66 ^a	37.51 ^b	39.82 ^a	40.39 ^a	38.92 ^a	39.06 ^a	39.87 ^a	39.91 ^a	38.95 ^a	38.51 ^b	39.77 ^a	39.75 ^a
AoD (deg)	5.48 ^b	7.50 ^a	5.65 ^b	5.71 ^b	6.28 ^{ab}	6.26 ^{ab}	5.28 ^b	6.10 ^{ab}	6.5 ^a	6.65 ^a	5.90 ^{ab}	5.71 ^b
Dispersibility	11.43 ^a	7.90 ^c	9.26 ^b	10.72 ^a	13.49 ^a	10.21 ^b	9.13 ^{bc}	8.79 ^c	7.50 ^d	10.56 ^a	9.94 ^a	8.98 ^b
Flow Index	76.6 ^{ab}	77.52 ^a	76.49 ^b	76.61 ^{ab}	76.44 ^{bc}	77.67 ^a	77.44 ^{ab}	76.46 ^{bc}	76.02 ^c	77.10 ^a	76.69 ^a	76.62 ^a
Flood Index	55.62 ^{ab}	56.00 ^a	54.38 ^b	54.15 ^b	57.59 ^a	56.10 ^a	53.95 ^b	53.74 ^b	53.78 ^b	56.25 ^a	54.89 ^{ab}	53.97 ^b
L*	51.77 ^a	47.70 ^b	42.82 ^c	34.82 ^d	41.13 ^b	44.64 ^a	45.95 ^a	45.34 ^a	44.31 ^a	40.71 ^c	45.17 ^b	46.94 ^a
a*	13.89 ^c	15.32 ^b	16.21 ^a	16.47 ^a	15.67 ^b	15.49 ^b	16.25 ^a	15.35 ^b	14.61 ^c	16.69 ^a	15.56 ^b	14.16 ^c
b*	74.69 ^a	75.23 ^a	71.28 ^b	58.96 ^c	65.96 ^c	70.84 ^{ab}	72.83 ^a	71.14 ^{ab}	69.44 ^b	67.72 ^b	71.47 ^a	70.94 ^a

Values followed by the same superscript letter within each property and each parameter are not significantly different (P<0.05)