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Factors Influencing Feed Ingredient Flowability

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Abstract

Animal-based food products play a significant role in the current U.S. diet. In 2003, the total meat consumption per capita was 90.5 kg/year [U.S. Department of Agriculture (USDA) 2005]. Since the U.S. has a high consumption of animal-based food products, the animal feed ingredients are fundamentally important. The ingredients can affect not only the quality of the animal-based food products, but also the potential human health. The U.S. is the largest producer of animal feed in the world (Gill 2004). Feed ingredients might include grains, milling byproducts, added vitamins, minerals, fats/oils, and other nutritional and energy sources. And kinds of feed ingredients are produced to use, like DDGS and soybean meal. Recently, some co-products of energy production, like DDGS are used as feed ingredient worldwide. This kind of co-product is nutrient rich and meets the requirement of animal feed nutrition. Since these food ingredients are used worldwide, they must be transported a long distance to some domestic and international market. And sometimes they are stored for a long time before be used. So during transportation and storage, ingredients often became restricted. This is a major problem that can affect the quality of ingredients. These issue most likely results from many factors, including ingredients' moisture content, particle size, temperature and relative humidity of air or pressure. The objective of this study was to investigate potential factors affecting flowability of feeding ingredients, as well as examines the effect of three moisture content levels (10, 20 and 30% db) on the resulting physical and flow properties of feeding ingredients. Certain amounts of water were added to adjust moisture content of ingredients and Carr indices were used to quantify the flowability of each ingredient. The results showed that moisture content had significant effects on physical and flow properties. According to Carr indices, flowability generally declined with increased moisture content. Using these, the best condition can be found for transportation and storage to maintain the good quality for ingredients when they are used.

Keywords

Feeds, Moisture, Flow

Disciplines

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Comments

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Abstract. *Animal-based food products play a significant role in the current U.S. diet. In 2003, the total meat consumption per capita was 90.5 kg/year [U.S. Department of Agriculture (USDA) 2005]. Since the U.S. has a high consumption of animal-based food products, the animal feed ingredients are fundamentally important. The ingredients can affect not only the quality of the animal-based food products, but also the potential human health. The U.S. is the largest producer of animal feed in the world (Gill 2004). Feed ingredients might include grains, milling byproducts, added vitamins, minerals, fats/oils, and other nutritional and energy sources. And kinds of feed ingredients are produced to use, like DDGS and soybean meal. Recently, some co-products of energy production, like DDGS are used as feed ingredient worldwide. This kind of co-product is nutrient rich and meets the requirement of animal feed nutrition. Since these food ingredients are used worldwide, they must be transported a long distance to some domestic and international market. And sometimes they are stored for a long time before be used. So during transportation and storage, ingredients often became restricted. This is a major problem that can affect the quality of ingredients. These issue most likely results from many factors, including ingredients' moisture content, particle size, temperature and relative humidity of air or pressure. The objective of this study was to investigate potential factors affecting flowability of feeding ingredients, as well as examines the effect of three moisture content levels (10, 20 and 30% db) on the resulting physical and flow properties of feeding ingredients. Certain amounts of water were added to adjust moisture content of ingredients and Carr indices were used to quantify the flowability of each ingredient. The results showed that moisture content had significant effects on physical and flow properties. According to Carr indices, flowability generally declined with increased moisture content. Using these, the best condition can be found for transportation and storage to maintain the good quality for ingredients when they are used.*

Keywords: *Feeds, Moisture, Flow*

Introduction

Animal-based food products play a significant role in the current U.S. diet. In 2003, the total meat consumption per capita was 90.5 kg/year [U.S. Department of Agriculture (USDA) 2005]. Since the U.S. has a high consumption of animal-based food products, the animal feed ingredients are fundamentally important. The ingredients can affect not only the quality of the animal-based food products, but also the potential human health. The U.S. is the largest producer of animal feed in the world (Gill 2004). Feed ingredients might include grains, milling byproducts, added vitamins, minerals, fats/oils, and other nutritional and energy sources. Kinds of feed ingredients are produced to use for feeding, like distiller's dried grains with solubles (DDGS) and soybean meal. Recently, some co-products of energy production, like DDGS are used as feed ingredients worldwide. This kind of co-product is nutrient rich and meets the requirement of animal feed nutrition. Since these food ingredients are used worldwide, they must be transported a long distance to some domestic and international markets. And sometimes they are stored for a long time before being used. So during transportation and storage, ingredients often became restricted. This is a major problem that can affect the quality of ingredients. These issues most likely result from many factors, including ingredients' moisture content, particle size, temperature and relative humidity of air or pressure. The objective of this study was to investigate potential factors affecting flowability of feeding ingredients, as well as examines the effect of three moisture content levels (10, 20 and 30% db) on the resulting physical and flow properties of feeding ingredients. Certain amounts of water were added to adjust moisture content of ingredients and Carr indices were used to quantify the flowability of each ingredient. The results showed that moisture content had significant effects on physical and flow properties. According to Carr indices, flowability generally declined with increased moisture content. Using these, the best condition can be found for transportation and storage to maintain good quality for ingredient.

Factors influencing the flowability of feeding ingredients

Flowability is the ability of powders to flow. The flowability characteristic of a powder is affected by both the physical properties of the material and the specific processing conditions in the handling system (Particle Technology Labs, 2014). The flowability of a material is most likely affected by ingredients' moisture content, particle size, and relative humidity of the air. Also, there are some minor factors influencing flowability, like temperature and pressure.

Moisture content

Moisture content is a key factor affecting powder flowability. The effect of moisture on the flowability depends on the amount of water and its distribution. Ganesan et al. (2008) studied the flow properties of DDGS, and found that if moisture content increased, DDGS flowability decreased. The main property it affected was angle of repose. Based on their study, with the increase of moisture content, angle of repose increased, which mean DDGS flowability decreased. Bulk density of material and compressibility are other flowability index properties. They also related with moisture content. Generally bulk density decreases and the compressibility increases with an increase in moisture content (Moreira and Peleg, 1981; Yan and Barbosa-Canovas, 1997). Also, the material's moisture content influences physical properties. With the increase of a powder's moisture content, the adhesion (Craik and Miller, 1958) and cohesion (Moreira and Peleg, 1981) increase.

Particle size

Particle size of bulk solids is important for flowability and other physical properties. Increasing particle size will increase the flowability of a material (Fitzpatrick et al., 2004a, b). The increase of particle size causes the surface area per unit mass increases. Particle size is also important for compressibility of materials. If the particle size increases, the compressibility will increase (Yan and Barbosa-Canovas, 1997).

Relative humidity

Relative humidity of the air around the storage place also affects materials' properties. It cannot influence properties directly. When materials are exposed to humid air, materials will absorb water from around the environment. This leads to the increase of moisture content. Since the moisture content increase, angle of repose will increase. Flowability of materials reduces with an increase in the angle of repose.

Materials and Methods

DDGS, soybean meal, soy protein concentrate, NF8, soy protein isolate, cotton seed meal, pea bran, soy flour, pea protein, corn gluten meal and fish meal were stored at room temperature in the sealed plastic bags until needed. The moisture content of all samples were determined by putting them in oven at 135^{o}C for 2 hours to get rid of water. Then after determining the moisture content for all samples, the amount of water that was needed to increase specific amount of sample to selected moisture content levels (10%, 20%, 30% db) was calculated and water was added into sample.

Flowability-related properties

Angle of repose

Angle of repose is the angle between the horizontal and the slope of a heap of granular material dropped from some designated elevation. Angle of repose corresponds qualitatively to the flow properties of that material and is a direct indication of potential flowability (Carr, 1965). A material with a lower angle of repose means this material is more flowable (Carr, 1965). Angle of repose is considered as a common method to measure flow properties (Craik and Miller, 1958). Usually with the increase of moisture content, angle of repose increases. Figure 1 shows the equipment to measure angle of repose.

Figure 1. Angle of Repose Equipment

Bulk density

Bulk density is defined as the mass of particles that occupies a unit volume of a container. Bulk density of material is important for transportation and storage. There are two types of bulk density: aerated bulk density (ABD) and packed bulk density (PBD). ABD was determined by pouring a quantity of solid material into a specific volume container. This represented the bulk solid that has not been compressed. PBD is the bulk density of the material after it has been compressed. This represented the material’s actual bulk density in storage and transport. Particle size and moisture content are main factors affecting bulk density. Bulk density of material decreases with an increase of the particle size. Also increasing the relative humidity will increase the moisture content of material. This leads to a decrease of bulk density (Yan and Barbosa-Canovas, 1997). Figure 2 shows equipment to measure aerated bulk density and packed bulk density. For aerated bulk density, a 0.5 L container was used to measure. For packed bulk density, a 1 L container was used.

Figure 2. Equipment for bulk density measurement

Uniformity

The size and shape of the particles has a direct effect on a material's ability to flow. The coefficient of uniformity is a ratio between the screen size that will pass 60% of the sample and the screen size that will pass only 10% of the sample. The more uniform the mass of particles is in both shape and size, the more flowable it is likely to be. There is an index value for uniformity coefficient. The maximum index value is 100, which means the material flowability is very good. The smaller the uniformity value, the more homogeneous the particle sizes and shapes. A material that is more uniform will have a tendency to have better flowability than a material with a wide range of particle sizes.

Compressibility

Compressibility can be used to estimate the flowability of the material. After determining aerated and packed bulk densities, the compressibility of a material can be calculated by the equation:

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

Where: P is packed bulk density (kg/cm3); A is aerated bulk density (kg/cm3).

This parameter provides an indication of particle size and the overall flowability of the material. The greater the compressibility of a material, the less flowable it is (Carr, 1965). Bulk solids with a compressibility number less than approximately 18 percent are considered free flowing.

Other properties

Thermal properties

Thermal properties are the characteristics of a material that determine how it reacts when it is subjected to excessive heat or heat fluctuations over time. It includes thermal conductivity, thermal resistivity, specific heat, and thermal diffusivity. They were measured using a thermal meter.

Water activity

Water activity is the partial vapor pressure of water in a substance divided by the standard state partial vapor pressure of water. Water activity is a measure of the energy status of the water in a system. Usually for same material, increasing the moisture content will lead the water activity to increase. The number of water activity index varies from 0 to 1. They were measured using a water activity measurement meter.

Color

Color is very important when dealing with feeding ingredients. L * is lightness level, a* is the green - red level and b* is the blue - yellow level in the color solid. The color values were measured using a Minolta Chroma meter.

Statistical analysis

A total of 11 sample with four moisture content levels (original, 10%, 20%, 30%) were prepared. The total combination of treatment would be 44 (11*4). Triplicates were measured for each property and for each treatment combination.

Result and Discussion

Table 1 shows moisture content and water activity values for the feed ingredients as they were received. Table 2, on the other hand, shows results for the feed ingredients at specific moisture content levels.

Table 1. As-is moisture content and water activity for feed ingredients; table shows mean values with standard deviations in parentheses.

	moisture content (%)	water activity
soybean meal	10.70	0.5
	(0.01)	(0.01)
high protein DDGS	6.40	0.43
	(0.01)	(0.01)
soy protein concentrate	8.70	0.3
	(0.01)	(0.01)
NF8	6.50	0.27
	(0.01)	(0.01)
soy protein isolate	6.30	0.24
	(0.01)	(0.02)
cotton seed meal	10.70	0.54
	(0.01)	(0.01)
pea bran	8.90	0.31
	(0.01)	(0.01)
soy flour	8.90	0.28
	(0.01)	(0.04)
pea protein	8.90	0.33
	(0.01)	(0.02)
fish meal	6.90	0.4
	(0.01)	(0.01)
corn gluten meal	7.80	0.33
	(0.01)	(0.03)

Soybean meal

For the original sample, Table 1 shows the moisture content is 10.7%, and water activity is 0.57.

Since the original moisture content is greater than 10%, only 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, thermal conductivity (K), thermal resistivity (ρ), volumetric specific heat (C) and thermal diffusivity (D) were measured. Based on Table 2, only 30% moisture content had a significant effect on the thermal properties. With the moisture content from the original increased to 30%, thermal conductivity (K) increased from 0.14 to 0.76. Thermal resistivity (ρ) decreased from 735.5 to 394.47. Volumetric specific heat (C) ranged from 1.41 to 1.54 and thermal diffusivity (D) varied from 0.01 to 0.17.

Usually the samples seemed to be darker when the sample increased the moisture content. From the chromameter results, it was observed that the difference between treatments for soybean meal did exist. Table 2 shows that the brightness (L*) of soybean meal decreased from 76.23 to 56.44, the redness (a*) value decreased from 6.67 to -1.24 and the blue-yellow (b*) value decreased from 33.20 to 6.19, with the moisture content levels increased from original to 30%.

Flow properties analysis

For angle of repose, Table 2 shows that when the sample increased moisture content to 20%, AoR values did not change too much. But for 30% moisture content, AoR had a significant increase. The mean value of AoR ranged from 36.83 to 45.1. ABD and PBD decreased from 646.22 to 544.47 and 770.56 to 596.23 with the moisture content increased to 30%. Compressibility, which is calculated using ABD and PBD, was significantly affected by moisture content, but there were no clear trends. The mean values of compressibility varied from 7.41% to 16.13%. For the mass flow rate, Table 2 shows that it decreased from 281.84 to 215.2 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was affected by moisture content level, but there was no clear trend. The uniformity ranged from 2.00 to 2.15. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.09 to 1.27.

High protein DDGS

For the original sample, Table 1 shows the moisture content is 6.4%, and water activity is 0.43. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, only 30% moisture content had a significant effect on the thermal properties. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.12 to 0.16. Thermal resistivity (ρ) decreased from 855.17 to 628.53. Volumetric specific heat (C) increased from 1.07 to 1.44 and thermal diffusivity (D) did not have a significant change. The values varied from 0.07 to 0.11.

From the chromameter results, it was observed that the difference between treatments for high protein DDGS did exist, but for the original sample and 10% moisture content, the change was not significant. And for 20% and 30% moisture content, the change also was not significant. Table 2 shows that when the moisture content varied from the original to 30%, the brightness (L*) of high protein DDGS varied from 72.57 to 63.5, the redness (a*) value decreased from 9.67 to -3.09 and the blue-yellow (b*) value ranged from 42.73 to 16.05.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 20%, AoR values did not change too much. For 30% moisture content, AoR had a significant increase. The mean value of AoR ranged from 44.3 to 50.43. ABD did not have a significant change when the moisture content increased. The mean values varied from 461.93 to 484.54. And PBD decreased from 620.65 to 504.93 with the moisture content increased to 30%. Compressibility for high protein DDGS was significantly affected by moisture content, but there were no clear trends. The mean values of compressibility varied from 8.68% to 21.68%. For the mass flow rate, Table 2 shows that it decreased from 105.6 to 62.7 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was affected by moisture content level, but there was no clear trend. The uniformity ranged from 2 to 2.08. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.09 to 1.28.

Soy protein concentrate

For the original sample, Table 1 shows the moisture content is 8.7%, and water activity is 0.3. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, with the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.11 to 0.16. Thermal resistivity (ρ) decreased from 933.63 to 608.03. Volumetric specific heat (C) increased from 0.99 to 1.34 and thermal diffusivity (D) did not have a significant change. The values increased from 0.11 to 0.12.

From the chromameter results, it was observed that the difference between treatments for soy protein concentrate did exist, but for the original sample and 10% moisture content, the change was not significant. And for 20% and 30% moisture content, the change also was not significant. Table 2 shows that when the moisture content varied from original to 30%, the brightness (L*) of high protein DDGS varied from 97.92 to 78.51, the redness (a*) value ranged from 1.38 to 2.22 and the blue-yellow (b*) value decreased from 12.59 to -23.16.

Flow properties analysis

For angle of repose, Table 2 shows that when moisture content increased from original to 30%, AoR values did not change too much. The mean value of AoR ranged from 51.87 to 54.13. ABD had a significant change when the moisture content increased. The mean values decreased from 486.47 to 402.73. PBD decreased from 649.96 to 470.67 with the moisture content increased to 30%.

Compressibility for soy protein concentrate was significantly affected by moisture content, but there were no clear trends. The mean values of compressibility varied from 12.31% to 25.14%. For the mass flow rate, Table 2 shows that it decreased from 101.67 to 53.78 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was affected by moisture content level, but there was no clear trend. The uniformity ranged from1.41 to 1.61. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.14 to 1.36.

NF8

For the original sample, Table 1 shows the moisture content is 6.5%, and water activity is 0.27. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content of NF8 had a significant effect on the thermal properties. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.13 to 0.17. Thermal resistivity (ρ) decreased from 755.6 to 391.6. Volumetric specific heat (C) increased from 1.25 to 1.7 and thermal diffusivity (D) did not have a significant change. The values increased from 0.11 to 0.15.

From the chromameter results, it was observed that the difference between treatments for NF8 did exist, but for the original sample and 10% moisture content, the change was not significant. Table 2 shows that when the moisture content increased from the original to 30%, the brightness (L*) of high protein DDGS decreased from 73.67 to 44.81, the redness (a*) value decreased from 8.79 to 2.64 and the blue-yellow (b*) value decreased from 25.65 to 3.6.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 30%, AoR values did not change too much. The mean value of AoR ranged from 39.57 to 58.57. ABD had a significant change when the moisture content increased. The mean values decreased from 758.82 to 542.73. And PBD decreased from 1343.29 to 584.1 with the moisture content increased to 30%. Compressibility for NF8 was significantly affected by moisture content, but there were no clear trends. The mean values of compressibility varied from 5.13% to 47.19%. For the mass flow rate, Table 2 shows that it decreased from 607.31 to 501.13 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 4.00 to 4.15. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.05 to 1.77.

Soy protein isolate

For the original sample, Table 1 shows the moisture content is 6.3%, and water activity is 0.24. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had a significant effect on the thermal properties. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.09 to 0.22. Thermal resistivity (ρ) decreased from 1110 to 447.13. Volumetric specific heat (C) increased from 0.78 to 1.4 and thermal diffusivity (D) did not have a significant change. The values varied from 0.12 to 0.18.

From the chromameter results, it was observed that the difference between treatments for soy protein isolate was only exist on blue-yellow (b*) value, but for the original sample and 10% moisture content, the change was not significant. And for 20% and 30% moisture content, the change also was not significant. Table 2 shows that when the moisture content varied from the original to 30%, the brightness (L*) of high protein DDGS varied from 90.14 to 94.98, the redness (a*) value ranged from 1.16 to 1.72 and the blue-yellow (b*) value decreased from 18.01 to -21.95.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 30%, AoR values did not change too much. The mean value of AoR ranged from 53.5 to 54.9. ABD did not have a significant change when increased the moisture content. The mean values varied from 295.97 to 329.51. And PBD decreased from 449.66 to 347.53 with the moisture content increased to 30%. Compressibility for soy protein isolate was significantly affected by moisture content, but there were no clear trends. The mean values of compressibility varied from 14.78% to 26.68%. For the mass flow rate, Table 2 shows that it decreased from 149.9 to 98.37 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 2.01 to 2.14. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.17 to 1.37.

Cotton seed meal

For the original sample, Table 1 shows the moisture content is 10.7%, and water activity is 0.54. Since the original moisture content is greater than 10%, only 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had a significant effect on the thermal properties for cotton seed meal. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.12 to 0.16. Thermal resistivity (ρ) decreased from 804.97 to 615.2. Volumetric specific heat (C) increased from 1.25 to 1.41 and thermal diffusivity (D) increased from 0.1 to 0.12.

From the chromameter results, it was observed that the difference between treatments for cotton seed meal was only exist between original moisture content and 20%, but for 20% and 30% moisture content, the change was not significant. Table 2 shows that when the moisture content varied from the original to 30%, the brightness (L*) of high protein DDGS decreased from 42.12 to 30.69, the redness (a*) value ranged from 3.99 to 8.46 and the blue-yellow (b*) value decreased from 18.41 to 2.41.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 30%, AoR values did not change too much. The mean value of AoR ranged from 44.87 to 46.8. ABD had a significant change when increased the moisture content. The mean values decreased from 596.84 to 510.8. And PBD decreased from 722.25 to 597.23 with the moisture content increased to 30%. Compressibility for cotton seed meal was not significantly affected by moisture content. The mean values of compressibility varied from 13.16% to 17.36%. For the mass flow rate, Table 2 shows that it decreased from 639.57 to 545.72 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 4.00 to 4.11. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.15 to 1.21.

Pea bran

For the original sample, Table 1 shows the moisture content is 8.9%, and water activity is 0.31. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had an effect on the thermal properties. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.12 to 0.15. Thermal resistivity (ρ) decreased from 874.87 to 642.1. Volumetric specific heat (C) ranged from 0.95 to 1.13 and thermal diffusivity (D) did not have significant change. The values varied from 0.11 to 0.15.

From the chromameter results, it was observed that the difference between treatments for each ingredient did exist. Table 2 shows that when the moisture content varied from the original to 30%, the brightness (L*) of high protein DDGS varied from 59.61 to 81.06, the redness (a*) value ranged from -3.15 to 1.97 and the blue-yellow (b*) value decreased from 21.89 to -7.49.

Flow properties analysis

For angle of repose, Table 2 shows that when moisture content increased from original to 30%, AoR values increased a little. The mean value of AoR increased from 40.4 to 46.87. ABD did not have a significant change when increased the moisture content. The mean values decreased from 686.03 to 627.27. And PBD decreased from 691.75 to 640.67 with the moisture content increased to 30%. Compressibility for pea bran was not significantly affected by moisture content. The mean values of compressibility varied from 0.82% to 2.09%. For the mass flow rate, Table 2 shows that it decreased from 121.93 to 85.3 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 2.65 to 2.98. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.01 to 1.02.

Soy flour

For the original sample, Table 1 shows the moisture content is 5.8%, and water activity is 0.28. Since the original moisture content is lower than 10%, 10%, the 20% and 30% moisture content level was measured. But when increased the moisture content to 20%, soy flour became semi-solid. Only original and 10% moisture content was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had an effect on the thermal properties. With the moisture content increased from the original to 10%, thermal conductivity (K) increased from 0.11 to 0.12. Thermal resistivity (ρ) decreased from 937.3 to 882.99. Volumetric specific heat (C) increased from 1.02 to 1.05 and thermal diffusivity (D) increased from 0.11 to 0.12.

Table 2 shows that when the moisture content varied from original to 10%, the brightness (L*) of soy flour decreased from 92.92 to 75.32, the redness (a*) value decreased from -0.95 to -3.67 and the blue-yellow (b*) value decreased from 24.26 to 18.49.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from the original to 10%, AoR values did not change too much. It increased from 54 to 56.6. ABD decreased from 390.66 to 377.42. And PBD decreased from 535.26 to 496.03 with the moisture content increased to 10%. Compressibility for soy flour decreased from 26.97% to 23.9%. For the mass flow rate, Table 2 shows that it decreased from 98.48 to 85.35 with the increase of moisture content to 10%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 2.84 to 2.96. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.31 to 1.37.

Pea protein

For the original sample, Table 1 shows the moisture content is 8.9%, and water activity is 0.33. Since the original moisture content is lower than 10%, 10%, the 20% and 30% moisture content level was measured. But when increased the moisture content to 30%, soy flour became semi-solid. Only original, 10% and 20% moisture content was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had an effect on the thermal properties. With the moisture content increased from original to 20%, thermal conductivity (K) ranged from 0.10 to 0.16. Thermal resistivity (ρ) decreased from 954.97 to 622.03. Volumetric specific heat (C) increased from 0.85 to 1.21 and thermal diffusivity (D) increased from 0.12 to 0.13.

Table 2 shows that when the moisture content varied from original to 20%, the brightness (L*) of pea protein decreased from 94.43 to 88.98, the redness (a*) value decreased from 1.63 to -3.6 and the blue-yellow (b*) value decreased from 24.44 to -3.6.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 20%, AoR values increased from 49.97 to 55.17. ABD decreased from 391.08 to 365.47. And PBD decreased from 452.43 to 395.93 with the moisture content increased to 20%. Compressibility for pea protein decreased from 13.55% to 7.69%. For the mass flow rate, Table 2 shows that it decreased from 133.25to 98.10 with the increase of moisture content to 20%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 2.00 to 2.09. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.08 to 1.16.

Fish meal

For the original sample, Table 1 shows the moisture content is 6.9%, and water activity is 0.40. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had a significant effect on the thermal properties. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.11 to 0.35. Thermal resistivity (ρ) decreased from 896.07 to 296.23. Volumetric specific heat (C) increased from 1.10 to 2.19 and thermal diffusivity (D) did not have significant change. The values increased from 0.10 to 0.15.

From the chromameter results, it was observed that the difference between treatments for fish meal did exist. Table 2 shows that when the moisture content varied from original to 30%, the brightness (L*) of fish meal decreased from 46.88 to 32.06, the redness (a*) value decreased from 6.54 to 0.87 and the blue-yellow (b*) value decreased from 22.81 to 1.54.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 30%, AoR values changed a little. The mean value of AoR increased from 53.33 to 59.33. When increased the moisture content, the mean values of ABD decreased from 556.43 to 486.43. And PBD decreased from 639.01 to 577.17. Compressibility for fish meal was affected by moisture content, but there were no clear trends. The mean values of compressibility varied from 12.92% to 15.72%. For the mass flow rate, Table 2 shows that it decreased from 276.02 to 188.98 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 1.99 to 2.14. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.15 to 1.19.

Corn gluten meal

For the original sample, Table 1 shows the moisture content is 7.8%, and water activity is 0.33. Since the original moisture content is lower than 10%, the 10%, 20% and 30% moisture content level was measured.

Physical properties analysis

For the thermal properties, based on Table 2, moisture content had a significant effect on the thermal properties. With the moisture content increased from original to 30%, thermal conductivity (K) increased from 0.11 to 0.16. Thermal resistivity (ρ) decreased from 911.83 to 634.23. Volumetric specific heat (C) ranged from 1.04 to 1.26 and thermal diffusivity (D) did not have significant change. The values increased from 0.10 to 0.13.

From the chromameter results, it was observed that the difference between treatments for corn gluten meal did exist. Table 2 shows that when the moisture content varied from original to 30%, the brightness (L*) of high protein DDGS decreased from 69.38 to 61.14, the redness (a*) value decreased from 7.36 to -8.14 and the blue-yellow (b*) value ranged from 37.58 to 54.9.

Flow properties analysis

For angle of repose, Table 2 shows that when the moisture content increased from original to 30%, AoR values did not change too much. The mean value of AoR increased from 43.53 to 46.20. When increased the moisture content, the mean values of ABD decreased from 547.83 to 487.87. And PBD decreased from 561.15 to 504.97 with the moisture content increased to 30%. Compressibility for corn gluten meal was not significantly affected by moisture content. The mean values of compressibility varied from 1.18% to 3.39%. For the mass flow rate, Table 2 shows that it decreased from 183.21 to 107.27 with the increase of moisture content to 30%. Based on Table 2, uniformity of soybean meal was significantly affected by moisture content level, but there was no clear trend. The uniformity ranged from 1.98 to 2.12. There was not a significant effect on the HR value for the different moisture content level. The HR value ranged from 1.01 to 1.04.

Table 2. Properties data for feed ingredients; table shows mean values and standard deviations.

		Thermal properties				Color									
	Moisture Content (%)	k	ρ	C_p	D	L*	a*	b*	AoR (°)	ABD (g/L)	PBD (g/L)	Uniform-ity	Compres-sibility (%)	HR	Mass flow (g/s)
soybean meal	as-is	0.14	735.50	1.42	0.09	76.23	6.67	33.20	38.03	646.22	770.56	2.00	16.13	1.19	281.84
	SD	0.00	5.66	0.01	0.00	2.06	0.77	1.55	5.06	4.11	8.82	0.04	0.01	0.02	25.06
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	0.14	717.90	1.41	0.01	67.92	-1.62	6.95	36.83	572.87	618.70	2.07	7.41	1.08	248.08
	SD	0.00	3.03	0.00	0.00	6.46	0.33	1.79	2.41	7.89	4.25	0.03	0.01	0.01	16.28
	30	0.76	394.47	1.54	0.17	56.44	-1.24	6.19	45.10	544.47	596.23	2.15	8.68	1.10	215.20
	SD	0.01	7.11	0.01	0.00	2.71	0.15	0.62	2.87	5.56	6.65	0.02	0.00	0.00	10.25
high protein DDGS	as-is	0.12	855.17	1.07	0.11	71.82	9.67	42.73	44.70	486.09	620.65	2.00	21.68	1.28	105.60
	SD	0.01	43.11	0.06	0.01	3.40	0.68	2.53	4.68	2.85	5.02	0.03	0.01	0.01	10.38
	10	0.13	792.43	0.12	0.10	72.57	7.58	35.53	44.30	484.54	617.21	2.03	21.49	1.27	97.19
	SD	0.00	3.08	0.00	0.00	1.10	0.11	0.91	2.71	0.88	8.11	0.01	0.01	0.01	10.63
	20	0.13	754.87	1.32	0.07	63.50	-2.65	16.05	46.00	487.33	535.70	2.02	9.02	1.10	84.85
	SD	0.00	6.14	0.01	0.05	4.65	0.37	1.05	2.79	5.15	4.35	0.02	0.02	0.02	7.90
	30	0.16	628.53	1.44	0.11	69.38	-3.09	18.0	50.43	461.93	504.93	2.08	8.50	1.09	62.70

							6								
	SD	0.01	3.80	0.00	0.00	1.42	0.57	2.19	3.06	7.92	6.65	0.00	0.02	0.02	13.71
soy protein concentrate	as-is	0.11	933.63	0.99	0.11	97.92	1.38	12.59	51.87	486.47	649.96	1.41	25.14	1.34	101.67
	SD	0.00	40.31	0.07	0.00	1.35	0.21	0.68	6.40	11.21	9.44	0.01	0.02	0.04	13.11
	10	0.13	795.48	1.15	0.11	95.63	1.66	9.39	53.33	462.90	627.31	1.53	26.20	1.36	102.66
	SD	0.00	9.03	0.00	0.00	1.17	0.42	0.23	1.72	5.20	11.18	0.02	0.01	0.02	11.55
	20	0.15	666.80	1.30	0.12	78.51	2.22	-24.13	53.13	437.57	499.00	1.61	12.31	1.14	76.78
	SD	0.00	11.87	0.03	0.00	2.65	0.05	0.64	4.68	9.15	11.56	0.01	0.00	0.00	7.04
	30	0.16	60.03	1.34	0.12	81.12	1.69	-23.16	54.12	402.73	470.67	1.54	14.43	1.17	53.78
	SD	0.01	6.55	0.01	0.00	2.66	0.16	1.06	2.91	6.37	6.37	0.00	0.00	0.01	9.67
NF8	as-is	0.13	755.60	1.25	0.11	73.67	8.79	25.65	39.57	758.82	1343.29	4.00	43.51	1.77	607.31
	SD	0.00	21.73	0.02	0.00	2.51	0.28	1.58	2.75	8.25	7.29	0.01	0.01	0.03	26.61
	10	0.14	695.69	1.35	0.11	65.44	8.53	21.80	44.60	688.06	1302.92	4.15	47.19	1.89	602.60
	SD	0.00	6.72	0.05	0.00	1.89	0.98	0.49	2.54	5.01	14.42	0.02	0.01	0.03	19.55
	20	0.17	575.30	1.50	0.12	55.06	3.11	6.93	44.00	578.80	610.10	4.05	5.13	1.05	543.98
	SD	0.00	8.32	0.00	0.00	3.70	0.18	0.42	2.61	7.82	4.11	0.03	0.01	0.01	21.04
	30	0.25	391.60	1.70	0.15	44.81	2.64	3.60	48.57	542.73	584.10	4.08	7.08	1.08	501.13
	SD	0.01	4.15	0.00	0.00	0.32	0.14	0.44	1.16	6.86	5.55	0.02	0.01	0.01	11.46
soy protein isolate	as-is	0.09	1110.00	0.78	0.12	92.93	1.72	18.10	53.83	329.51	449.66	2.01	26.68	1.37	149.90
	SD	0.01	95.25	0.03	0.01	1.35	0.06	0.45	2.70	13.74	7.06	0.01	0.04	0.08	19.85
	10	0.11	965.57	0.85	0.14	94.98	1.95	14.94	53.50	321.77	424.69	2.06	24.21	1.32	134.76
	SD	0.01	11.48	0.04	0.01	3.12	0.51	0.76	2.01	6.73	12.32	0.03	0.02	0.03	17.89
	20	0.18	571.97	0.96	0.18	91.82	1.16	-21.79	53.83	327.53	384.53	2.14	14.84	1.17	125.56
	SD	0.01	20.81	0.06	0.02	4.95	0.08	0.63	2.96	14.01	1.21	0.00	0.01	0.02	13.62
	30	0.22	447.13	1.40	0.16	90.14	1.37	-21.95	54.90	295.97	347.33	2.09	14.78	1.17	98.37
	SD	0.01	10.06	0.01	0.01	5.36	0.52	0.63	2.31	4.36	8.44	0.02	0.01	0.01	10.72
cotton seed meal	as-is	0.12	804.97	1.25	0.10	42.12	8.46	18.41	46.80	596.84	722.25	4.00	17.36	1.21	639.57
	SD	0.00	19.68	0.03	0.00	0.43	0.29	0.35	1.55	6.70	6.87	0.02	0.02	0.02	52.57
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	20	0.15	678.17	1.29	0.11	39.38	3.99	3.27	44.87	558.50	643.13	4.06	13.16	1.15	564.33
	SD	0.01	41.31	0.04	0.00	2.04	0.16	0.48	2.16	10.25	8.21	0.01	0.01	0.02	21.73
	30	0.16	615.20	1.41	0.12	30.69	4.39	2.41	45.63	510.80	597.23	4.11	14.47	1.17	545.72
	SD	0.01	8.19	0.01	0.00	1.03	0.11	0.27	2.95	7.50	7.02	0.03	0.01	0.01	12.05
pea bran	as-is	0.12	874.87	1.13	0.11	77.81	1.93	21.89	40.40	686.03	691.75	2.83	0.82%	1.01	121.93

	SD	0.00	44.48	0.02	0.00	1.18	0.03	0.64	1.90	12.08	16.58	0.00	0.01	0.01	9.68
	10	0.13	853.49	1.09	0.11	74.00	1.97	18.14	44.50	660.71	673.51	2.74	1.89	1.02	123.46
	SD	0.00	9.86	0.01	0.00	2.07	0.44	0.66	2.20	5.26	9.43	0.03	0.01	0.01	7.91
	20	0.14	707.30	0.95	0.15	81.06	-3.15	-6.83	45.70	660.42	668.53	2.65	1.22	1.01	97.25
	SD	0.00	4.65	0.01	0.00	1.54	0.03	0.65	3.64	17.24	15.46	0.01	0.00	0.00	9.87
	30	0.15	642.10	1.06	0.15	59.61	-1.05	-7.49	46.87	627.27	640.67	2.98	2.09	1.02	85.30
	SD	0.01	6.00	0.01	0.00	1.54	0.11	0.62	2.60	11.08	7.00	0.04	0.01	0.00	9.74
soy flour	as-is	0.11	937.30	1.02	0.11	92.92	-0.95	24.26	54.00	390.66	535.26	2.84	26.97	1.37	98.48
	SD	0.00	26.79	0.04	0.00	0.16	0.04	0.25	2.35	6.67	12.93	0.00	0.03	0.06	20.77
	10	0.12	882.99	1.05	0.12	75.32	-3.67	18.49	56.60	377.42	496.03	2.96	23.90	1.31	85.35
	SD	0.00	7.08	0.00	0.01	1.71	0.83	0.12	3.54	7.39	6.46	0.01	0.02	0.04	9.36
	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
pea protein	as-is	0.11	954.97	0.85	0.12	94.35	1.63	24.44	49.97	391.08	452.43	2.00	13.55	1.16	133.25
	SD	0.00	12.67	0.05	0.00	0.96	0.16	1.10	1.33	4.44	6.27	0.00	0.01	0.02	23.94
	10	0.10	898.62	0.92	0.12	93.56	1.37	21.13	50.43	382.98	432.97	2.04	11.35	1.13	143.96
	SD	0.00	6.56	0.01	0.00	2.10	0.29	0.57	2.90	4.54	4.68	0.01	0.02	0.02	14.99
	20	0.16	622.03	1.21	0.13	88.98	-3.60	-7.57	55.17	365.47	395.93	2.09	7.69	1.08	98.10
	SD	0.00	3.59	0.01	0.00	5.12	0.43	1.53	2.39	7.97	8.09	0.02	0.01	0.01	10.83
	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
fish meal	as-is	0.11	896.07	1.10	0.10	46.88	6.54	22.81	53.33	556.43	639.01	1.99	12.92	1.15	276.02
	SD	0.01	47.40	0.03	0.00	0.17	0.07	0.15	2.08	9.67	4.91	0.01	0.02	0.02	11.71
	10	0.12	831.26	1.23	0.10	43.12	4.56	17.36	55.23	538.91	624.21	2.03	13.65	1.16	267.28
	SD	0.00	6.42	0.02	0.00	2.19	0.42	0.33	3.29	4.20	7.79	0.03	0.02	0.02	11.41
	20	0.30	504.43	1.65	0.12	32.78	0.91	3.97	56.60	514.80	596.37	2.14	13.68	1.16	214.33
	SD	0.01	21.34	0.02	0.00	1.92	0.12	0.62	2.26	12.48	7.00	0.02	0.02	0.02	10.99
	30	0.35	296.23	2.19	0.15	32.06	0.87	1.54	59.33	486.43	577.17	2.07	15.72	1.19	188.98
	SD	0.01	9.55	0.01	0.00	1.74	0.17	0.10	2.10	7.72	7.74	0.04	0.00	0.00	8.71
corn gluten meal	as-is	0.11	911.83	1.04	0.10	69.38	7.36	54.90	43.53	547.83	561.15	1.98	2.35	1.02	183.21
	SD	0.00	22.09	0.02	0.00	0.29	0.03	0.30	2.20	4.20	11.78	0.02	0.02	0.02	19.66
	10	0.13	848.05	1.14	0.12	65.49	4.54	51.76	44.70	529.60	535.94	2.02	1.18	1.01	165.26
	SD	0.01	11.78	0.02	0.01	2.47	0.39	0.35	3.20	6.52	5.80	0.01	0.00	0.00	9.51
	20	0.16	648.07	1.26	0.12	64.08	-9.13	37.58	45.07	517.63	527.67	2.07	1.90	1.02	136.64
	SD	0.00	5.57	0.02	0.00	5.22	0.77	3.30	2.96	9.89	9.42	0.03	0.01	0.01	15.46

	30	0.16	634.23	1.23	0.13	61.14	-8.14	41.64	46.20	487.87	504.97	2.12	3.39	1.04	107.27
	SD	0.00	5.36	0.00	0.00	3.33	0.70	1.66	2.19	8.67	8.97	0.01	0.00	0.01	6.51

Conclusions

This study has shown that moisture content significantly affected many properties of feeding ingredients. For the physical properties, color values were influenced by the moisture content. And the thermal properties decreases with the increase of moisture content. For flowability properties, moisture content had effect on ABD, PBD, AoR, uniformity, compressibility and mass flow. According to these data, feeding ingredients flowability generally declined with an increase in moisture content.

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