# Mean particle size: Evaluation of variation within industry processed grains and determination of the effect of laboratory grinding

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## ABSTRACT

This study aims to determine how the mean particle size (MPS) of corn grain, soybean meal, and full fat soybeans used for dairy cattle feed varies throughout industry samples and the effect laboratory grinding through 6-mm and 4-mm screens has on the MPS. Samples were collected from multiple feed mills in the Midwest, analyzed for original MPS and classified into fine, medium, or coarse accordingly. Original samples were then ground through 6-mm and 4-mm screens and MPS was measured. Samples that were classified as fine did not have significant reduction in their MPS when ground through either screen. Medium classified samples saw a significant reduction in MPS when ground through a both screens. Coarse classified samples saw the largest reduction in MPS by both a 6-mm and 4-mm screens, reducing the original samples by over 50% from their original MPS. This study indicates that laboratory determination of digestibility may not reflect well the digestibility of the original feedstuffs if classified as medium or coarse because of MPS reduction through sample grinding in the laboratory prior to digestibility assays.

## INTRODUCTION

In dairy cattle diets, corn is a vital component due to its energy content provided primarily by the starch it contains (Huntington, 1997). Fredin et al. (2015) reported that diets that include adequate starch have an advantage in milk and fat-corrected milk yields over those insufficient in starch. A key factor that contributes to starch digestibility is particle size (Fredin, 2015). Rémond et al. (2004) reported that corn with greater kernel processing had reduced MPS and increased the digestibility in both the rumen and the small intestine. Reduced MPS also increased milk yield and content of protein in milk (Rémond et al., 2004). Yu et al. (1998) reported that varying corn processing by feed mills, including coarse-ground, fine-ground, steam-flaked, or steam-rolled, resulted in digestibility and milk production differences in dairy cows fed these processed corn grains (Yu, 1998).

Various laboratory evaluations are used to determine the potential digestibility of feedstuffs for ruminant animals. Evaluations include in vitro or in situ determination of dry matter (DM), starch and (or) neutral detergent fiber (NDF) digestibility. These evaluations usually require the grinding of samples in the laboratory to homogenize feedstuffs and reduce sampling error with small sample sizes (0.5-1.0 grams; Richards, 1995). NDF digestion measurements are usually preformed using a 1-mm screen. Grains differ though in being ground through either a 6-mm or 4-mm screen in an effort to maintain particle size differences between grain samples, understanding that particle size and surface area can affect starch digestibility. The MPS of grains from feed mills, which use varying processing methods, roller mills, hammer mills, varying screens, etc. likely differ and in some cases may be larger than 4 or 6 mm MPS. In this case, laboratory processing at 4 or 6 mm in turn may reduce MPS and possibly distort the starch digestibility measurements relative to the actual feed samples (Nardi et al., 2014). The objectives of this study were to utilize commercial corn grain, soybean meal, and full fat soybean samples ranging in MPS to determine if laboratory grinding during sample preparation for digestibility determination distorted original MPS. These scientific findings will be useful to assess the significance of in vitro or in situ digestibility measurements in comparison to in vivo animal digestion and performance.

## METHODS

### Experimental Design

For this study, 12 different samples from 3 different types of feedstuffs, including corn grain, soybean meal, and full fat soybeans. The 12 samples represented varying grinding methods and roller mill gap settings from commercial feed mills. Corn grain processing methods used included: dry ground, cracked, or rolled corn. Multiple commercial roller settings were incorporated. Soybean samples were either whole roasted full-fat soybeans or rolled soybean meal. For each sample, three separate samples/treatments were created: the original samples and laboratory ground to pass both 6-mm and 4-mm screens. For analysis, the feed-mill samples were categorized as fine, medium or coarse samples based on our determination of their original sample MPS. The fine (less than 900 µm) group consisted of 5 corn grain samples. The medium (900-2000 µm) group consisted of 3 corn grain samples and 2 soybean meal samples. Original samples that had a measured MPS greater than 2000 µm were categorized into the coarse group, which contained one corn grain and one full-fat soybean sample.

### Grinding Procedures

Each sample was divided randomly using a stainless steel riffle-splitter to assure homogeneity in splits into 3 separate samples, which were then distributed, into individual bags with approximately 110 g of sample in each. For the 6-mm and 4-mm samples, the feed was ground through a Wiley Centrifugal Mill to pass the corresponding screen size. After all samples were processed through the Wiley Mill, each sample, including the original, was dry sieved for particle size determination.

## Particle Size Measurements

Particle size of the samples was determined using a Ro-Tap Shaker with 8 USA Standard Test Sieves E-11 Spec. The eight sieves were ordered from top to bottom as follows: 2 mm, 1mm, 850 µm, 500 µm, 250 µm, 150 µm, 106 µm, and a bottom pan for any particles smaller than the last sieve. Each sample was sieved for 10 minutes using the Ro-Tap Shaker. After sieving, each sieve plate was weighed, and the weight of sample in each sieve was recorded. The proportion of sample weight in each sieve was then used to calculate MPS using a log normal distribution.

## Data Analysis

For analysis, the data were organized into corresponding feedstuff groups: corn grain, soybean meal, and full fat soybeans. The average MPS, standard deviation, minimum MPS, and maximum MPS were calculated for the original sample, 4-mm, and 6-mm grinds which are organized in Table 3. For each screen size, the MPS reduction and percent reduction from the original was calculated which are noted in Table 4. For statistical analysis, a t-test was used to determine the significance of the sample group (fine, medium, and coarse) reduction after each grind against the original sample mean.

# RESULTS

## Original Samples

The original corn grain samples separated into the MPS groups of fine, medium, and coarse. The fine group of original corn samples had an average MPS of 765.49 µm with a standard deviation of 88.31 µm. Table 1 displays the data for all corn grain samples used, with the fine ground sample having the lowest MPS of the group at 630.26 µm. The largest MPS of the group was the 864.57 µm from the non-descript roller mill setting "-5" sample.

Three original corn grain samples categorized into the medium group had an observed average of 1219.91 µm. The standard deviation for these samples was 276.07. The largest sample in the group, resulting from a non-descript "10" setting at commercial roller mill, resulted in a MPS of 1525.24 µm. The smallest sample, labeled "900", had a MPS of 987.93 µm.

The "cracked corn" sample was the only corn grain sample with a MPS over 2000 µm and placed in the coarse group. Its MPS was 2582.03 µm.

The soybean meal consisted of 2 samples, both of which were categorized as medium. One sample had an observed MPS of 1026.26 µm, and the other 944.85 for an average MPS of

985.54 µm. The one full fat soybean sample had a MPS of 3081.88 and was thus classified as coarse.

## 6-mm Laboratory Grinding

When grinding samples through a 6-mm screen a reduction in MPS from the original sample was observed across all groups. The average MPS of fine corn grain samples was 731.59 µm and not significantly different from the original sample mean (p-value = .49) with a standard deviation of 99.83 µm. The group MPS was reduced on average by 33.89 µm with a standard deviation of 42.80 µm. An interesting result is found within the "Fine Corn River Valley 6-mm" sample, which showed no decrease in MPS from the original sample. This sample therefore had the lowest reduction in MPS as presented in Table 1. The largest reduction in MPS was observed as 100.69 µm (12.30%) in the "FC IAS" also presented in Table 1.

The medium corn grain samples had an observed average MPS of 964.72 µm (p-value < .05) with a standard deviation of 90.06 µm. Observed MPS reductions for the group averaged 255.19 µm with a standard deviation of 112.60 µm. The largest MPS reduction from the original sample in the medium group was observed as 478.73 µm (31.39%) in the "10" sample as presented in Table 1. The smallest reduction was observed in the "900" sample at 119.73 µm (12.12%).

The coarse corn grain sample had an observed reduction of 1345.35 µm (52.10%) from the original when ground through the 6-mm screen (Figure 2).

The soybean meal and full fat soybeans also had significant MPS reductions. The soybean meal samples were reduced in MPS by an average of 97.09 µm, with a group MPS of 888.47 µm (p-value = .06). The sample with the larger original MPS of 1026.26 had the greatest reduction of 147.63 µm compared to the 46.55 µm reduction of the finer sample with an original MPS of 944.85. The full fat soybean sample was reduced 1672.03 µm from its original MPS of 3081 µm, which is a 54.25% reduction (Figure 2).

## 4-mm Laboratory Grinding

Further reduction of the corn grain samples was observed when grinding through a 4-mm screen. In the fine group, the average MPS across the group was 681.77 µm (p-value < .05) with a standard deviation of 41.05 µm. In terms of reduction of the original, the group had an observed average MPS reduction of 83.71 µm with a standard deviation of 52.14 µm (Table 4). The largest observed MPS reduction was 138.94 µm (16.07%) in the sample generically labeled "-5". The smallest MPS reduction was observed in the "fine grind" sample, which was reduced 13.87 µm (2.20%). An interesting note for the 4-mm "fine grind" sample is that it was reduced less than the 6-mm "fine grind" sample that was reduced 52.68 µm (8.36 µm). This was the only sample in the study across both corn grain and soybean that the 6-mm screen had a higher observed MPS reduction. The "fine grind" sample also had the lowest observed original MPS of all samples at 630.26 μm.

The medium group of 4-mm corn grain had an observed MPS average of 841.82 μm (p-value < .05) with a standard deviation of 29.32 μm. The group MPS was reduced by an average of 378.08 μm with a standard deviation of 255.58 μm. The "10" sample displayed the largest MPS reduction of 666.58 μm (43.7%) from the original MPS of 1525.24 μm and the "900" sample had the smallest observed MPS reduction of 179.99 μm (18.22%) from the original 987.93 μm MPS (Table 4).

The one coarse corn grain sample had an observed MPS reduction of 1718.64 μm from the original MPS of 2582.03 μm, which is a 66.56% reduction in MPS (Figure 2).

For soybeans samples ground through a 4-mm screen, a further MPS reduction was observed. The soybean meal samples had an average MPS reduction of 207.22 μm, with a group average of 778.34 μm (p-value = .14). Both samples had similar MPS reductions from their original sample with a standard deviation of 9.61 μm. For the full fat soybean sample, a 2099.64 μm MPS reduction was observed (Figure 2). This resulted in a new MPS of 982.24 μm, which is 31.87% of the original sample.

**DISCUSSION**

When analyzing the results of the fine corn grain industry samples (MPS < 900 μm), the samples fell within a narrow range with an observed deviation from the mean of 88.31 μm. Figure 1 displays this change in MPS across the fine corn grain samples. The grinding of these samples through both 6-mm and 4-mm screens present a reduction that falls under that deviation of 33.89 μm and 83.71 μm respectively. Knowing this, the grinding of fine samples would not reduce samples below the industry average of MPS for fine samples. Therefore, grinding would not affect the accuracy of these samples in laboratory starch digestion assays.

Corn grain samples categorized as medium had greater reductions when processed through both laboratory screens. Grinding the samples through a 6-mm screen brought an average of 964.72 μm, which would still be classified as a medium sample. However, the smallest sample was 868.20 μm and therefore classified as fine. If original samples used for scientific studies had a MPS near 1000 μm, they could be reduced by a 6-mm screen to that of a fine sample. All original corn grain samples processed through a 4-mm screen were reduced to below 900 μm, changing the classification from medium to fine. If a medium feed sample was used for digestion measurements after being ground through either a 6-mm or 4-mm screen, there could be a possibility that the data would not correlate to the original sample.

Soybean meal samples, both classified as medium, had reductions from both screen sizes that brought their MPS below 900 μm (Figure 3). Both samples had original MPS close to 1000 μm, so the drop to a fine classification was not a large reduction. One sample was only reduced

46.55 μm by the 6-mm screen, and this was enough to have an MPS below 900 μm. With the 4-mm screen grind, a much greater MPS reduction was observed with the average of 207.22 μm, and laboratory studies should be cautious about grinding soybean meal samples through the smaller screen for digestion assays. The data suggests that a 6-mm grind would not be as detrimental to digestion assays with the small reductions from the original, but could be if the original sample had a large enough MPS.

Using a coarse industry sample ground through either laboratory screen sizes present the most cause for concern. The coarse corn grain sample had its original MPS halved by the 6-mm screen, thereby categorizing it as a medium sample. The 4-mm screen reduced the MPS to that of a fine sample with an MPS of 863.39 μm. Any digestion data collected from ground samples would not be correlated back to the original coarse sample with such a large reduction.

Overall, the data suggest that grinding fine industry samples of corn grain through a 6-mm screen is not necessary, as it does not present a significant change in MPS. For all other groups of feedstuff, samples ground through either a 6-mm or 4-mm screen could change the MPS of the sample and affect digestibility results. More research needs to be done with regard to the effect of varying MPS on in vitro or in situ starch digestibility measurements to fully understand how significant a problem the reduction of MPS during laboratory grinding is for the accuracy of laboratory digestibility measurements.

## CONCLUSIONS

Laboratory grinding of commercially ground grains has a significant impact on the resulting MPS. The extent of particle size reduction is dependent on the original sample's MPS. For fine grains, grinding through a 6-mm screen will most likely not raise a cause for practical concern, but a 4-mm screen presented statistically significant reductions in MPS. Medium grains presented more significant reductions for both 6-mm and 4-mm grinds. This reduction should be accounted for during laboratory digestion assays to ensure an accurate correlation to the original samples. With coarse samples being reduced to over half their MPS, it would be unrealistic to correlate any digestion data from samples ground through either screens back to their original sample MPS. In future research, laboratories should take note of the original particle size of their samples for the best correlation to actual rumen digestibility. A recent study investigated this point and also suggested that surface area rather than MPS may be a measure better related to rumen digestibility (Goeser, 2016). More intensive research must be done to determine the effect of changes in MPS below 1500 μm to completely understand the significance of this study.

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**Table 1:** Mean particle size (microns) data for corn grain samples with reductions and percent reductions.

| **Fine** | | | | **Medium** | | | | **Coarse** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample** | MPS | MPS Reduction | % Reduced | **Sample** | MPS | MPS Reduction | Percent Reduced | Coarse | MPS | MPS Reduction | % Reduced |
| -10 Original | 749.56 | - | - | 5 Original | 1146.54 | - | - | CC Original | 2582.03 | - | - |
| -10 6mm | 745.04 | 4.52 | 0.60% | 5 6mm | 979.44 | 167.11 | 14.58% | CC 6mm | 1236.68 | 1345.35 | 52.10% |
| -10 4mm | 700.04 | 49.52 | 6.61% | 5 4mm | 858.86 | 287.68 | 25.09% | CC 4mm | 863.39 | 1718.64 | 66.56% |
| -5 Original | 864.57 | - | - | 10 Original | 1525.24 | - | - | | | | |
| -5 6mm | 852.82 | 11.75 | 1.36% | 10 6mm | 1046.51 | 478.73 | 31.39% | | | | |
| -5 4mm | 725.63 | 138.94 | 16.07% | 10 4 mm | 858.67 | 666.58 | 43.70% | | | | |
| FC IAS Original | 818.73 | - | - | 900 Original | 987.93 | - | - | | | | |
| FC IAS 6mm | 718.04 | 100.69 | 12.30% | 900 6mm | 868.20 | 119.73 | 12.12% | | | | |
| FC IAS 4mm | 693.49 | 125.23 | 15.30% | 900 4mm | 807.94 | 179.99 | 18.22% | | | | |
| FC RV Original | 764.31 | - | - | | | | | | | | |
| FC RV 6mm | 764.46 | -0.15 | -0.02% | | | | | | | | |
| FC RV 4mm | 673.30 | 91.00 | 11.91% | | | | | | | | |
| FG Original | 630.26 | - | - | | | | | | | | |
| FG 6mm | 577.58 | 52.68 | 8.36% | | | | | | | | |
| FG 4mm | 616.39 | 13.87 | 2.20% | | | | | | | | |

Reductions in table are the decrease in MPS of the sample from the original.
Fine MPS < 900 μm
Medium MPS = 900-2000 μm
Coarse MPS > 2000 μm

**Table 2:** Mean particle size data (microns) for soybean meal (SBM) and full fat soybean samples with reductions and percent reductions.

| **SBM (Medium)** | | | | **Full Fat Soybean (Coarse)** | | | |
|---|---|---|---|---|---|---|---|
| **Sample** | Particle Size | MPS Reduction | % Reduction | **Sample** | Particle Size | MPS Reduction | % Reduction |
| SBM IAS Original | 1026.26 | - | - | Roasted Beans Original | 3081.88 | - | - |
| SBM IAS 6mm | 878.62 | 147.63 | 14.39% | Roasted Beans 6mm | 1409.85 | 1672.03 | 54.25% |
| SBM IAS 4mm | 825.84 | 200.42 | 19.53% | Roasted Beans 4mm | 982.24 | 2099.64 | 68.13% |
| SBM Triangle Ag Original | 944.85 | - | - | | | | |
| SBM Triangle Ag 6mm | 898.31 | 46.55 | 4.93% | | | | |
| SBM Triangle Ag 4mm | 730.84 | 214.01 | 22.65% | | | | |

Reductions in table are the decrease in MPS of the sample from the original.
Fine MPS < 900 μm
Medium MPS = 900-2000 μm
Coarse MPS > 2000 μm

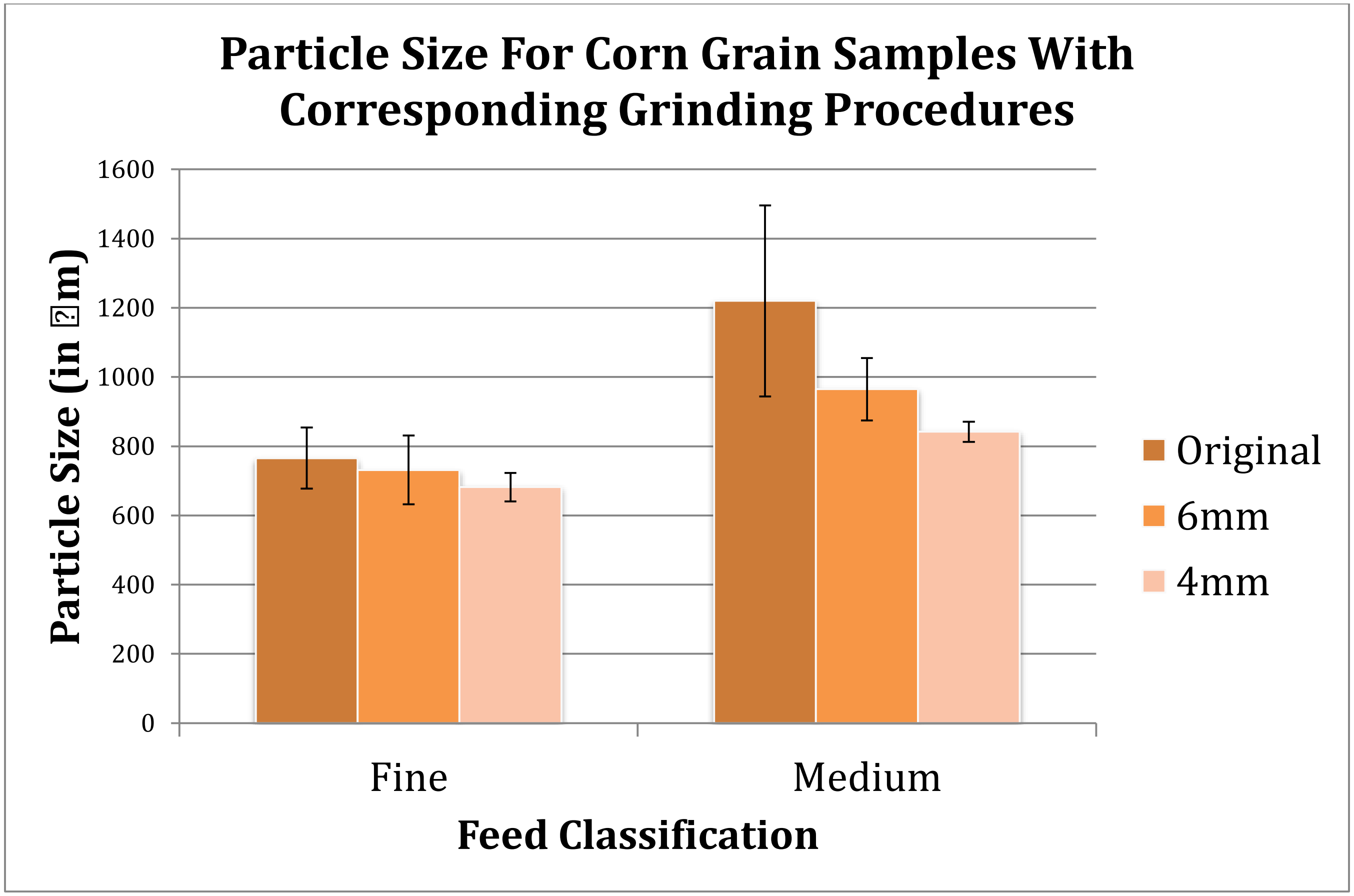


**Figure 1.** Particle size change from original to corresponding grinding screens for fine and medium corn grain samples. Bars in the graph indicate the mean of the MPS for each group. Error bars in graph denote the standard deviation from the mean of the samples.

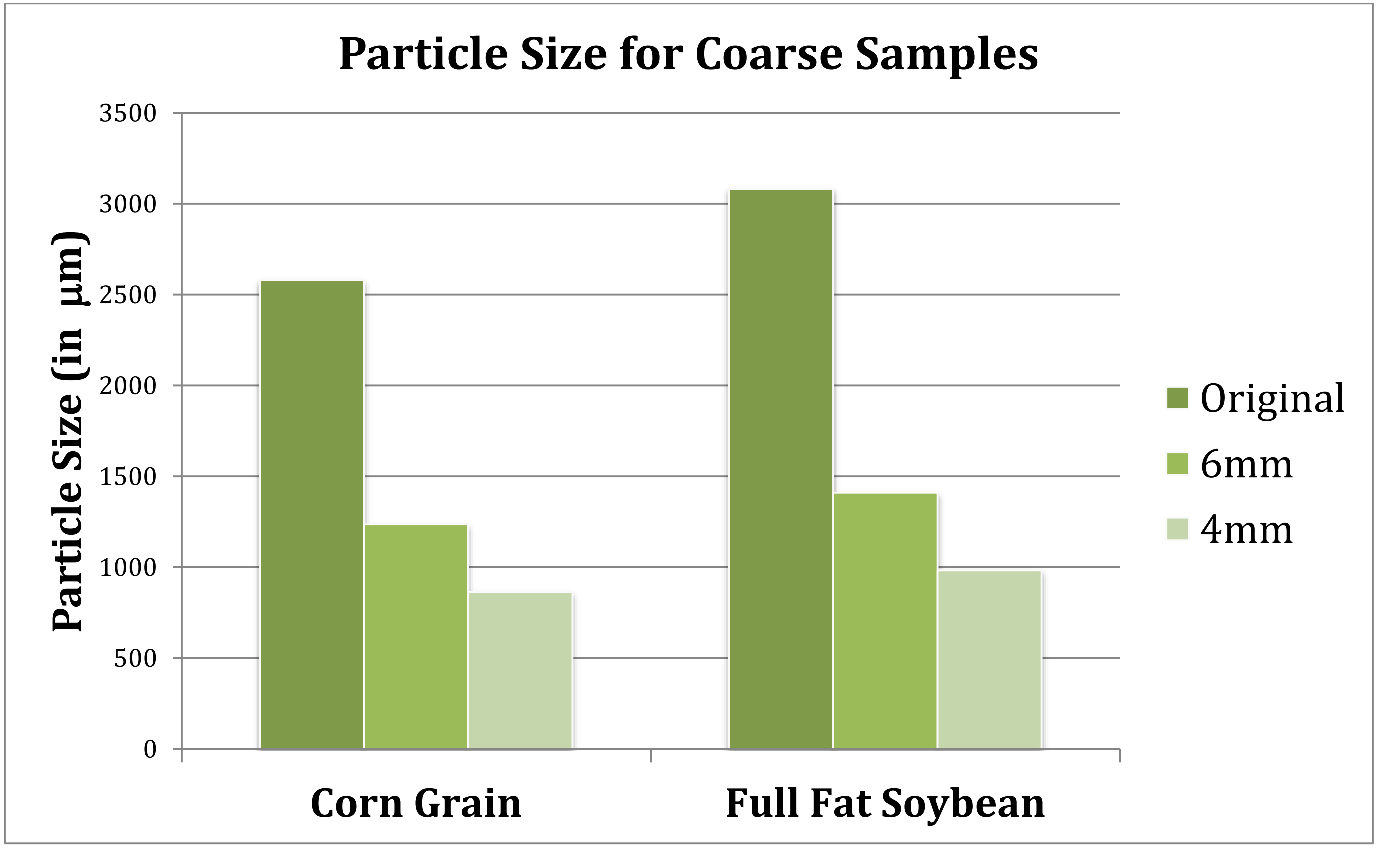


**Figure 2.** Change in particle size of coarse samples of corn grain and full fat soybean. Each type of feedstuff contained one sample, and this graph shows the regression of that sample through laboratory grinding. Reductions for corn grain 6-mm and 4-mm were 1345.35 and 1718.64 µm, respectively. For full fat soybean the reduction was 1672.03 and 2099.64 µm, respectively.

**Table 3**: Mean particle size (microns) of corn grain and soybean meal samples with average, standard deviation, minimums, and maximums.

| | Corn | | SBM |
|---|---|---|---|
| Feed Classification | **Fine** | **Medium** | **Medium** |
| Original average | 765.49 | 1219.91 | 985.54 |
| Original std deviation | 88.31 | 276.07 | 57.57 |
| Original min | 630.26 | 987.93 | 944.85 |
| Original max | 864.57 | 1525.24 | 1026.26 |
| 6mm average | 731.59[NS] | 964.72[a] | 888.47[b] |
| 6mm std deviation | 99.83 | 90.06 | 13.92 |
| 6mm min | 577.58 | 868.20 | 878.62 |
| 6mm max | 852.82 | 1046.51 | 898.31 |
| 4mm average | 681.77[a] | 841.82[a] | 778.34[b] |
| 4 mm std deviation | 41.05 | 29.34 | 67.18 |
| 4mm min | 616.39 | 807.94 | 730.84 |
| 4mm max | 725.63 | 858.86 | 825.84 |

P-values test against original average
Averages with p-values < .05 are denoted [a]
Averages with p-values < .15 are denoted [b]
Non statistically significant averages are denoted [NS]

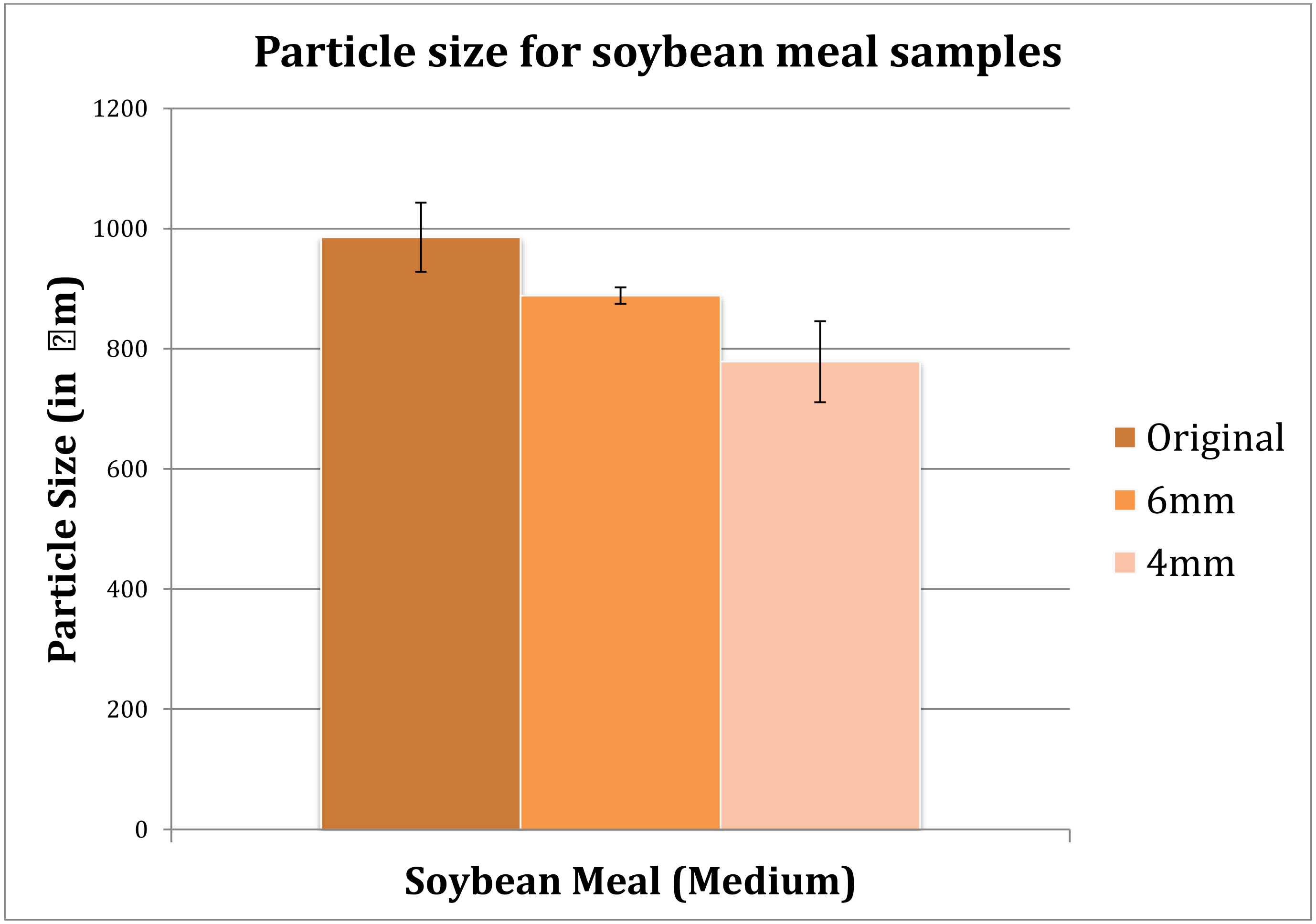


**Figure 3:** Change in particle size of soybean meal samples, all of which were classified as medium. Bars indicate the average of samples. The group consisted of two samples and the error bars on the graph indicate the standard deviations from the mean.

**Table 4:** Reduction data (microns) for corn grain and soybean meal (SBM) groups (sample size > 1).

| | **Corn** | | **SBM** |
|---|---|---|---|
| Feed Classification | **Fine** | **Medium** | **Medium** |
| 6mm average | 33.89 | 255.19 | 97.09 |
| 6mm std. deviation | 42.8 | 195.03 | 71.47 |
| 6mm min | -0.15 | 119.73 | 147.63 |
| 6mm max | 100.69 | 478.73 | 46.55 |
| 4mm average | 83.71 | 378.08 | 207.22 |
| 4mm std. deviation | 52.14 | 255.58 | 9.61 |
| 4mm min | 13.87 | 167.11 | 200.42 |
| 4mm max | 138.94 | 666.58 | 214.01 |

Reductions in table are the decrease in MPS of the sample from the original.
Fine group MPS < 900 μm
Medium group MPS = 900-2000 μm