Investigating Soybean Test Weights for Cultivar Development

by

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ABSTRACT

Soybean test weight is a characteristic that has recently become of interest to both plant breeders and growers. The official weight of a bushel of soybean is 60 lbs bu^{-1} (75.7 kg hL^{-1}). This standard is used to convert the weight displayed on screen at grain elevator to calculate the number of bushels contained in a load. Typically, when the test weight falls below 54 lbs (68.4 kg), the grower may receive a discounted payment. Due to little information being available on the components of test weight and what measurement devices would be most accurate and efficient for a breeding program, further investigation was warranted. For this thesis; i) three test weight measurement devices; a Perten Aquamatic 5200, a Mini-GAC Plus, and a Volumetric Instrument were evaluated for both accuracy and efficiency and ii) an investigation of agronomic and seed components conducted to determine their effect on test weight. Data was collected and received from cooperators, who grew the 2019 and 2020 Southern Soybean Uniform Tests, conducted by the USDA. Analysis of genotype, environment, and genotype x environment were conducted and correlations with oil, protein, seed size and plant height to determine their effect on test weight. All three instruments were found to provide adequate test weight measurements, but the Volumetric is considered the most efficient when moisture and temperature measurements are not required. The results indicated a consistent negative correlation of oil and seed size with test weight across a range of cultivars and maturity groups. Average test weights were found to be consistently less than 75.7 kg hL^{-1}, with some individual cultivars exceeding this target. Future studies should focus on further understanding the role and interactions of oil, protein, seed size, and seed weight to develop breeding strategies for maintaining test weights while improving yield.

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LIST OF ABBREVIATIONS

bu	Bushel
GAC	Mini GAC Plus
GxE	Genotype by Environment
hL	Hectoliter
MG	Maturity Group
K	Potassium
kg	Kilograms
lbs	Pounds
NIT	Near Infrared Transmittance
Perten	Perten Aquamatic 5200
TW	Test Weight
USDA	United States Department of Agriculture

CHAPTER 1

LITERATURE REVIEW

The inherent value of any crop is determined by human benefit and is converted into economic value based on the crop's role in the market. Soybean [(*Glycine max* (L.) Merr.] is a major row crop of great economic value and importance not only to the US but also the world (Hymowitz, 2004). Soybean is sold through a commodity-based market system that assumes uniformity (United Soybean Board, 2020) and determines value based on specific composition and the associated end products. Due to soybean being high in both oil and protein, it is processed in order to use them effectively in specific products (United Soybean Board, 2018). In terms of production, the US was ranked the number one country at approximately 123 million tons (FAO, 2020) in 2018, while Alabama produced on average 2.69 tons per hectare, with a value estimated at $123 million dollars (NASS, 2020).

Domestication

By the first century A.D. soybean was documented in south and central China and the Korean peninsula which is considered its center of origin. By the 1400s, soybean was cultivated throughout Asia (Hymowitz, 2004). Soybean was first grown in the United States in 1765 (Hymowitz, 2004). In 1915, soybean oil was produced at a cottonseed oil mill in North Carolina. However, most of the soybean processed in this way were imported from Manchuria China. The cottonseed mills saw potential for the crop and began contracting growers to produce the crop in 1917. This caused the number of acres of soybean to increase. During World War II, China's supply routes to export soybean were cut off due to the war. In addition, Japan invaded China which created an opportunity for the US to become a larger producer and exporter of soybean oil, a major by-product of the crop (Ganzel, 2020). Since World War II, U.S. soybean production increased sharply and expanded into foreign markets.. Prior to the war, it was grown primarily for forage (Probst, A.H. and Judd, 1973). In 1970, about 50% of the US soybean crop was exported as oilseed, oil, or protein meal (Kromer, 1973).

Domestically soybean is used mostly for meal and oil. About 98% of meal goes to animal feed, while the remaining 2% is used to produce food for humans. For oil, about 88% is used for human consumption (primarily cooking oil), while the remaining portion is used as an alternative for petroleum oil (biodiesel) (Wills, 2013). In 2019,the US harvested 74.9 million acres and exported $18 billion dollars of soybean (Foreign Agricultural Service, 2020) (NASS, 2021).

Protein content is 40-41% on average, and efforts to develop soybean with higher protein content have been slowed by its negative relationship to yield. Oil content ranges from 8.1 to 24.0%, and the relationship between oil and protein is negatively correlated (Krishnan, 2001; Medic et al., 2014). Soybean seed composition varies in the US as cultivars grown in the Northern and Western growing regions, such as Illinois, contained 1.5-2.0% less protein and 0.2-0.5% more oil than varieties grown in the southern states, such as Alabama (Hurburgh et al., 1990). Regional differences may have an effect on oil and protein content. One study involving soybean grown in different regions of Argentina found that protein and oil are both positively correlated with altitude, protein is negatively correlated with latitude and precipitation, while oil is negatively correlated with temperature and precipitation (Maestri et al., 1998). In addition, varieties grown in the Northern region of the US were determined to have more breeding potential to produce higher oil content than their Southern counterparts. The cause of these variations were likely due to the genotype and the environment (Piper and Boote, 1999). One of the main components of oil that gives value is fatty acid content and composition. Content is the amount per unit area. Composition is what makes up the different fatty acids. These determine oil quality which in turn determines other factors such as nutritional value, flavor, oxidative stability, and melting point (Medic et al., 2014).

Test Weight

Test weight (TW) has recently become a characteristic of interest to both farmers and public soybean breeders. It is a measurement of weight per unit volume (bulk density) (Haaland, 1980) and one of the factors taken into consideration when soybeans are sold. It is the weight of a certain volume of grain that is required to fill a Winchester bushel, for soybean it is 35.24 liters. The legal weight per bushel is the amount number of pounds of grain that is required for a bushel with no regard for volume and is the basis for which grain is typically bought and sold (United States Department of Agriculture, 1953). The legal weight per bushel varied by state (Smith, 1940).The purpose of measuring TW is to convert the weight displayed on the scale recorded by the grain elevator into the number of bushels contained in the load (Davidson, 2018a). The Winchester bushel is a fixed volume that is assumed to weigh 60 lbs (75.7 kg hL^{-1}) for soybeans (Canadian Grain Commission, 2019). While most TW measurement at grain elevators weigh between 56 (70.8 kg hL^{-1}) and 58 (73.3 kg hL^{-1}) lbs, a grower is discounted if the values fall below 54 lbs (68.4 kg hL^{-1}) (Davidson, 2018b). The main reason that the load of soybean is docked when TW is low at the grain elevator is due to the lower amount of product in a given storage area. Both the storage bins and the processing equipment are limited by volume, meaning that both storage bins and extraction equipment can hold less mass with low TW than a normal one (Davidson, 2018b). There are no premiums for TW higher than 60 lbs bu^{-1} or (75.7 kg hL^{-1}) (United States Department of Agriculture Farm Service Agency, 2019).

Soybean Grading Standards

The US Grain Standards Act was passed in 1916. It established uniform standards for kind, class, quality, and condition for corn, wheat, rye, oats, barley, flaxseed, sorghum, and soybean. The act allowed individuals designated by the Secretary of Agriculture to carry out the inspections for the standards and grant an official grain designation. The official grain designation is a numerical or sample designation, specified in the standards relating to kind, class, quality, and condition of the grain (Office of the Law Revision Council of the US House of Representatives, 2020).

The market determines the price of the crop that could potentially be paid to the grower. Grading is used to help determine a given price paid to the grower by the grain elevator. There may or may not be a Federal Grain Inspection Service certified inspector present at an individual elevator (United States Department of Agriculture Agricultural Marketing Service Federal Grain Inspection Service, 2020). There are five grades for soybean: numbers 1 to 4 and the 5th grade is USDA sample grade. As the rank number increases, the number of defects and problematic materials increase, and the amount paid to the grower decreases. Grade 1 gives the highest selling price to the grower, while USDA sample grade gives the lowest selling price. USDA sample grade is given to TW that does not meet the criteria for the other grades (United States Department of Agriculture Agricultural Marketing Service Federal Grain Inspection Service, 2007). TW was a factor in grading until 2007, but is now only used as a guideline (GIPSA, 2006). Grade 1 soybean TW is 56 lbs, grade 2 is 54 lbs , grade 3 is 52 lbs, and grade 4 is 49 lbs (U.S. Soybean Export Council, 2005). A number of factors are considered when determining a grade including, moisture, damaged seed, purple mottling or stains, splits, and foreign material. If the moisture content of the soybean exceeds 13%, then the grower may be docked due to quality issues from excess moisture. Damaged kernels are defined by the USDA as any soybean or pieces of soybean that are severely damaged by disease, frost, disease, heat, weather, mold, and insects (United States Department of Agriculture Marketing and Regulatory Programs Agricultural Marketing Service Federal Grain Inspection Service, 2020). Damaged soybeans have a reduced storage life for the seed, and a yield reduction in oil processing. Foreign material is all the matter that passes through an 8/64 round hole sieve other than soybean. This would include dirt, plant parts, or weed seeds. "Purple mottled or stained" is a discoloration of the soybean by a fungus or by dirt or dirt-like substances including non-toxic inoculants or substances. Other foreign materials include animal waste, castor beans, crotalaria seeds, stones, glass, and other unidentifiable objects Splits are soybean with more than one fourth of the bean removed and are not damaged by other means (United States Department of Agriculture Marketing and Regulatory Programs Agricultural Marketing Service Federal Grain Inspection Service, 2020).

Components of Test Weight

Many seed components could influence TW. However, there is little information on which seed traits or environmental factors such as weather, disease, insects, or planting date affect TW. There is TW information in other crops such as maize and wheat. In maize, it has been shown that TW has been linked with the hardness and durability of the seed. It also reported that that density and TW for maize are positively correlated (Pomeranz et al., 1986). Another study reported that maize kernel characteristics that determine durability, such as bulk density, true density, and thousand kernel weight are negatively linked to moisture (Babic et al., 2013). There is a link with seed density, moisture and TW for maize and wheat. One study examined the relationship between seed density, TW, and moisture in both maize and wheat. In wheat, when wheat moisture levels were 3-8%, seed traits such as seed density and TW increased slightly then decreased as moisture increased to 24%. In maize, results that were similar to the wheat portion of the study occurred when moisture levels were between 10-30%, however when the maize moisture was higher than 30% seed density started to increase, while TW continued to decrease (Nelson, 1980).

In terms of oil and protein content, TW may be a valuable indicator. High seed densities in soybean have been linked with high protein content. While low densities are linked to high oil content (Hartwig and Collins, 1962). In soybean, both bulk density and true density are negatively linked to moisture levels. One study, in which moisture levels were 8-16%, reported that as the moisture level increased in soybean, the bulk density and true density decreased at a linear rate (Kibar and Öztürk, 2008). Liu et al. (2019) reported for five genotypes that when the moisture content was increased from 5% to 18% TW decreased 0.20 to 0.25 kg hL^{-1} per unit moisture. The conclusion from this study is that TWs must be standardized to the same moisture level across various genotypes, environments, and experiments to make an accurate comparison (Liu et al., 2019).

A positive correlation between protein and TW was found but is somewhat inconsistent in the experiments and locations it was conducted in(Liu et al., 2019). In contrast, oil was found to have a consistent negative relationship with TW and verified in by McNeece et al., 2021. In addition, sucrose was positively correlated with TW (Liu et al., 2019). Lastly, seed size was found to be negatively correlated with TW , but was inconsistent with the experiments conducted in the study (Liu et al., 2019). The positive relationship between protein and TW suggests that it would be possible to breed a soybean cultivar for these traits. However, producing a cultivar with high protein content without reducing yield has been an issue. Some progress has been made with the development of cultivars such as Prolina which have a higher-than-average protein content and substantially improved yield (87% seed yield compared to the control cultivar) (Wilson and Burton, 1999). Other germplasm releases produced by breeders such as R05-1415 and R05-1771 contained a protein content ranging from 46.3-46.9% with only a 6-9% reduction in seed yield compared to the control cultivar 5002T (Chen et al., 2011). The germplasm releases TN03-350 and TN04-5321 were found to have an elevated protein content ranging from 43.1-43.9% without a reduction in seed yield. (Panthee and Pantalone, 2006). This would suggest that in the future breeders may produce a high protein content soybean with little to no yield loss (Medic et al., 2014). Moreover, the negative correlation between oil content and TW was small over different environments suggesting that a high oil and high TW soybean is possible in some environments (Liu et al., 2019).

Genotype x Environment Interactions

The interactions between the genotype and the environment can have a significant impact on soybean performance. Variability in the population is necessary when breeding for certain traits. (Bernardo, 2012a) All the variables encountered when producing a crop are collectively described as the environment. Identifying and classifying interactions between the genotype and the environment is of great importance in crop improvement. Examples of the environmental conditions include weather. Weather conditions that may be good for one crop plant may not be good for another (Visher, 1940). For example, hay grown in Indiana tends to thrive in warm springs, wet Mays, and cool wet Junes. Maize grown in Indiana however tends to do well in the late spring and early summer, but typically requires more rainfall than the state receives on average (Visher, 1940).

Genotype x environment interaction (GxE) can be determined by growing different genetic populations and quantifying a certain characteristic, such as yield, and ranking the different genotypes based on their performance in different environments. (Allard and Bradshaw, 1964; Becker and Leon, 1988; Zhe et al., 2010).). This interaction may reduce the breeding response to selection (Fehr, 1991). GxE interactions are important to a plant breeder because they affect most decisions of a breeding program including the breeding strategy, choice of germplasm, and identifying the most relevant testing environments (De Leon et al., 2016). For example, one maize hybrid developed by a breeding program may be grown and tested in hundreds or thousands of environments before it is ultimately released. The performance of these cultivars and varieties depends on the degree of GxE interaction, that occurs when there is a difference in the performance of the genotypes across the various environments (Bernardo, 2012b). In addition developing varieties for specific purposes is determined by understanding the genotype with the interactions of predictable environmental factors. For example unique cultivars may be needed for different soil types, or planting dates. GxE is also used to determine the allocation of resources across locations and years. (Fehr, 1991). In addition, the genotype, environment, and GxE interactions are significant in other crops. In wheat for example, one study found a significant GxE interaction for grain yield and TW (Khazratkulova et al., 2015). Another study found that the effects of the environment were greater than the effects of the genotype for traits such as TW (Li et al., 2013). Another study on wheat reported a slightly larger effect of genotype on TW than environment, and the effect GxE on TW was smaller than the genotype and environment but still significant (Sissons et al., 2018). In maize, there was a larger environment and genotype effect on TW than GxE but the GxE effect was still significant (Vázquez-Carrillo et al., 2016). In oats, one study found that there was a significant GxE effect on all traits measured including TW (Doehlert et al., 2001). It is also important to note that the influence of GxE on TW varies across crops even though it is significant. One study found that the effect of

GxE on TW at the same locations was significant in sorghum but not maize (Chiremba et al., 2011). For soybean, a study conducted with three different experiments for heritability on TW found that GxE is significant for TW and that broad sense heritability was present in the populations ranging from 0.84 to 0.97 (Liu et al., 2019). Another study reported that in all of seven trials the genotype effect was significant for TW, while the environment was significant for TW in five of the seven trials. In addition, the GxE interaction was found to be significant for TW in all trials. Broad sense heritability was also reported for TW with a range of 0.62 to 0.95 (McNeece et al., 2021).

Biotic and Abiotic Stress Effect on Test Weight

Biotic stresses include insects, and diseases. Insect damage may reduce the TW due to a reduction in seed weight, and a reduction in major seed components such as oil and protein. An example of this is the soybean aphid, one of the major insect pests (Venette and Ragsdale, 2004). One study reported that in 2003 during V5 and R2, the oil content decreased by 0.06 and 0.07% and 0.08% and 0.1% in 2004 for every 1000 aphids added to the plant per day during peak aphid number. (Beckendorf et al., 2008). It also found, protein increased 0.1 and 0.2 % and R2 in 2003 and 2004 with every 1000 aphids added to the plant per day (Beckendorf et al., 2008). Stink bugs are another problematic pest in soybean. Stinkbugs feed on the seed pod and can cause empty, discolored, and smaller seed (Scott and Aldrich, 1970). One study examined the damage stink bug, *Nezara viridula* (L.), *Piezodorus guildinii* (W.) and *Euschistus heros* (F.) and reported a significant reduction in seed quality in plants by all three species. It also reported that the control in the study had an average seed weight of 10.7 grams. In contrast the soybean plants infested by *N. viridula* , *P. guildinii* and *E. heros* had an average weight of 1.4, 1.3, and 4.5 grams for seeds considered to be good quality (Corrêa-Ferreira and De Azevedo, 2002).

Different diseases in soybean may also influence TW due to diseases being capable of reducing components such as oil and protein. One major disease in soybean that may affect TW is purple seed stain, which is caused by *Cercospora kikuchii* and reduces the seed quality by staining the seed coat a dark purple color(Roy, 1976). Another study found a significant reduction in seed weight samples stained 76-100% (Prasanth, 2007). The study also reported a decrease in oil content of 4.59 to 12.16% compared to healthy seeds. The largest decreases were found in samples containing 75% or more diseased seeds, but oil contents in seeds stained 26-50% and 76-100% were similar. The study also noted that protein content was reduced by 3.85-11.75% with the 11.75% reduction being in samples with 76-100% diseased seed (Prasanth, 2007). In addition the fungus *Phomopsis longicolla*, which causes the diseases pod and stem blight in soybean has been shown to reduce TW (Hepperly, 1978).

Abiotic stress includes drought, heat, salt stress, and nutrient deficiency, such as potassium. Drought is a meteorological phenomenon that typically results in crop injury due to a lack of available water (Purcell and Specht, 2004). Heat stress is defined as an event with extreme temperatures above the optimum range of plants (Ihsan et al., 2019). One study reported in that the combination of drought and heat stress caused ~4.2 billion dollars of damage for crops in the US (Mittler, 2006). Water availability has been shown to have an effect on the vegetative biomass, seed weight and size, and yield. Water stress during late stages of seed fill can cause a reduction in seed size. Drought or water stress during the early seed-filling stages however can reduce the number of seeds in the pod (Meckel et al., 1984). One experiment found that water stress caused a reduction in seed size for soybean (Brevedan and Egli, 2003). Another study examined the effect of water stress on soybean. It found that under severe moisture stress at R5 the vegetative weight was reduced 20 to 50% and the yield was reduced by 21 to 46%. It also found that the number of seeds per unit area was reduced by 16 to 50% (Meckel et al., 1984). Another experiment, conducted during two growing seasons, found under extreme drought, protein content increased by 11.4 and 5.1%. It also found that drought conditions reduced oil content by 10.3 and 4.8% in the two seasons. The study also reported slight effect on the fatty acid composition of the oil content (Dornbos and Mullen, 1992).

There have been mixed reports about the effect of high temperatures on oil and protein content. One study found that oil content increased by as temperatures increased. Oil content increased the most when temperatures were between 24 and 27°C during the day and 19-24°C at night. Protein was found to remain stable between 18-30°C and increased further when the daytime temperature increased to 33 °C (Wolf et al., 1982). Another study found that when the average temperature increased from 25 to 33°C during the R1-R8 growth stages, protein content to increase by 33 mg/g. Conversely, in soybean exposed to this temperature regimen, oil content decreased by 10 mg/g during R5-R8 and 12mg/g during R1-R8 (Gibson and Mullen, 1996). A third study found that if high temperatures occurred during seed fill, oil content increased (Naeve and Huerd, 2008). Another study found that increased temperatures from the R5 to R8 stage decreased protein and increased oil. They concluded that discrepancies between these studies may be due to the genetic improvement of the crop over the years (Mourtzinis et al., 2017).

High temperatures influence the concentration of different fatty acids in soybean seed. One study reported high temperatures decreased linolenic and linoleic acid as oleic acid increased. It noted that linolenic acid grown at 18°C in the day and 13°C at night had its levels at 16.4%. However, when the day and nighttime temperatures increased to 33°C and 28°C respectively, the linolenic acid levels dropped to 5.0%. Linoleic acid levels dropped from 55.8% under cooler temperatures to 40.3% under hot temperatures. It also reported that as temperatures increased oleic acid levels increased from 13.1% under cool temperatures to 38.7% under hot temperatures. The levels of stearic and palmitic acid levels remained stable (Wolf et al., 1982). This may be due to the reduction of various desaturase enzymes, those which regulate the production of fatty acids, in the seeds in these higher temperatures (Cheesbrough, 1989). Another study also reported that high temperatures reduced the amount of linoleic and linolenic acid levels in soybean seed by 11.1%, while oleic acid increased 10.0% in response to the high temperatures (Dornbos and Mullen, 1992). Under high temperatures, carbohydrate concentration has been shown to decrease. One study found that as the daytime temperature increased from 18 to 33°C and the nighttime temperature increased from 13 to 28°C, sugar content decreased from 8.1 to 3.6%. The resulting conclusion was that oil and sugar content have a negative correlation (Wolf et al., 1982).

Salt stress can affect oil and protein levels in the seed. One study found that both protein and oil levels decrease as salinity levels increase, but protein decreases at a higher rate than oil (Ghassemi-Golezani et al., 2010). Potassium is a nutrient vital to soybean growth and nutrient balance in the plant (deMooy, C.J., Pesek, John and Spaldon, 1973) and may also influence oil and protein content. One study reported that K reported in a soil test has a negative relationship to the protein to oil ratio in the seed (Anthony et al., 2012).

Management

When planting any crop, it is important to consider the various factors that may affect the value of the crop as a whole. These factors include maturity group, planting date, and seeding rate. Maturity groups are numbered from 000 to X and represent the area where a cultivar is best grown (Heatherly and Elmore, 2004). The maturity group is based on the daylength required for the plant before it achieves flowering (Garner and Allard, 1930). Both MG and planting date may affect the seed composition of the crop. One study conducted in Wisconsin and Minnesota using maturity groups 0.5-2.0 found that a late planting date resulted in high protein content. It also reported that an early planting date resulted in a high oil content (Mourtzinis et al., 2017). Similar results with oil and protein were seen in an study conducted in 1990 (Helms et al., 1990). Oil content may decrease if planted late, mostly due to the decline in temperature (Robinson et al., 2009).

Seeding rate can influence the vegetative growth. One study reported that higher seeding rates improved the vegetative and early reproductive growth when row spacing was widened (Chen and Wiatrak, 2011). Another study found seeding rate can also influence seed composition. Protein was positively correlated with seeding rates up to a threshold of 180,000 seeds per hectare. The decline beyond that rate was attributed to competition between plants for soil nutrients (Bellaloui et al., 2014).

Methods to Measure Test Weights

According to Matthew Reuss, Nashville Growmark FS, an agricultural retailer and grain elevator in Nashville, Illinois, (personal communication), TW is measured at the grain elevator when a farmer delivers a grain load onto a scale. Once the load is positioned on the scale, a probe with vacuum suction is placed inside the load and takes a set sample that is one bushel. From there the sample is placed in sieves to separate foreign material and splits. A quality rating is also taken during this process. Once cleaned, the elevator then places the sample in a TW instrument. The instrument used to determine the TW depends on the elevator’s preferences, but once that measure is acquired, the number of bushels contained is calculated. The price is then determined based on the market price, quality measure, and TW determination. (Matthew Reuss, 2019, Personal Communication). There are three common instruments used to measure TW in a research setting: Mini GAC Plus (GAC), Perten Aquamatic 5200 (Perten), and Volumetric instruments. The Mini GAC Plus developed by (DICKEY-john corporation), located in Auburn, Illinois, measures TW, moisture, and temperature of a sample. One advantage of the GAC is that it is a portable device, allowing the collection of measurements in the field. The results of the measurements are given to the user in seconds. The drawback is that the instrument auto calibrates after each use which is inefficient (DICKEY-john Corporation, 2017). The Perten Aquamatic 5200 (Perkin Elmer) located in Waltham, Massachusetts, measures moisture, specific weight, and temperature in seconds. An advantage of using this instrument is that it can measure multiple samples without being recalibrated manually. However, it is not portable and as a result cannot be used in the field (Perten Instruments, 2017). The volumetric instrument only measure TW for a sample. There is not a temperature or moisture level reading for the sample. The volumetric instrument consists of multiple components including a quarter kettle, a scale specifically designed to measure TW per bushel, a filling hopper, an overflow pan, and a stroker (Lee, 2013).

Objective

There is little information on which seed traits and environmental effects impact TW. Studies have shown the effects of environment on related traits such as protein and seed size, but not directly on TW. In addition, a breeding program processes hundreds or thousands of samples each year. Therefore, the primary objective is to investigate seed components as they relate to breeding and identify which traits a breeder should focus on to improve TW. The second objective is to determine which instrument would be most efficient for a breeding program.

References

Allard, R.W., and A.D. Bradshaw. 1964. Implications of Genotype-Environmental Interactions in Applied Plant Breeding 1 . Crop Sci. 4(5): 503–508. doi: 10.2135/cropsci1964.0011183x000400050021x.

Anthony, P., G. Malzer, S. Sparrow, and M. Zhang. 2012. Soybean yield and quality in relation to soil properties. Agron. J. 104(5): 1443–1458. doi: 10.2134/agronj2012.0095.

Babic, L.J., M. Radojein, I. Pavkov, M. Babic, J. Turan, et al. 2013. Physical properties and compression loading behaviour of corn seed. Int. Agrophysics 27(2): 119–126. doi: 10.2478/v10247-012-0076-9.

Beckendorf, E.A., M.A. Catangui, and W.E. Riedell. 2008. Soybean aphid feeding injury and soybean yield, yield components, and seed composition. Agron. J. 100(2): 237–246. doi:

10.2134/agronj2007.0207.

Becker, H.C., and J. Leon. 1988. Stability Analysis in Plant Breeding. Plant Breed. 101(1): 1–23. doi: 10.1111/j.1439-0523.1988.tb00261.x.

Bellaloui, N., A. Mengistu, E.R. Walker, and L.D. Young. 2014. Soybean seed composition as affected by seeding rates and row spacing. Crop Sci. 54(4): 1782–1795. doi: 10.2135/cropsci2013.07.0463.

Bern, C.J., and T.J. Brumm. 2009. Grain Test Weight Deception. Agric. Environ. Ext. Publ. 38(October). https://lib.dr.iastate.edu/extension_ag_pubs/38.

Bernardo, R. 2012a. Introduction. Plant Breeding for Quantitative. 2nd ed. Stemma Press, Woodbury,MN. p. 3–14

Bernardo, R. 2012b. Genotype x Environment Interaction. Plant Breeding for Quantitative Traits in Plants. 2nd ed. Stemma Press, Woodbury,MN

Boerner, E.. 1916. Bulletin No. 472:Improved Apparatus for Determining the Test Weight of Grain, with a Standard Method of Making the Test. Wa.

Brevedan, R.E., and D.B. Egli. 2003. Short Periods of Water Stress during Seed Filling, Leaf Senescence, and Yield of Soybean. Crop Sci. 43(6): 2083–2088.

Canadian Grain Commission. 2005. Test Weight Conversion Chart.

Canadian Grain Commission. 2019. Test weight for Canadian grains. Can. Gov. https://www.grainscanada.gc.ca/en/grain-quality/grain-grading/grading-factors/test-weight-grain.html (accessed 21 February 2021).

Chen, G., and P. Wiatrak. 2011. for the Southeastern Production System : I . Vegetation Indices.

doi: 10.2134/agronj2010.0153.

Chiremba, C., L.W. Rooney, and J.R.N. Taylor. 2011. Relationships between simple grain quality parameters for the estimation of sorghum and maize hardness in commercial hybrid cultivars. Cereal Chem. 88(6): 570–575. doi: 10.1094/CCHEM-06-11-0078.

Corrêa-Ferreira, B.S., and J. De Azevedo. 2002. Soybean seed damage by different species of stink bugs. Agric. For. Entomol. 4(2): 145–150. doi: 10.1046/j.1461-9563.2002.00136.x.

Davidson, D. 2018a. Understanding Test Weight | ILSoyAdvisor. Illinois Soybean Assoc. https://www.ilsoyadvisor.com/on-farm/ilsoyadvisor/understanding-test-weight (accessed 11 January 2021).

Davidson, D. 2018b. Test Weight Matters in 2019. Illinois Soybean Assoc. https://www.ilsoyadvisor.com/on-farm/ilsoyadvisor/test-weight-matters-2019 (accessed 29 May 2020).

deMooy, C.J., Pesek, John and Spaldon, E. 1973. Mineral Nutrition. Soybeans: Improvement ,Production ,and Uses. p. 267–337

Ding, J.-Q., J.-L. Ma, C.-R. Zhang, H.-F. Dong, Z.-Y. Xi, et al. 2011. QTL mapping for test weight by using F 2:3 population in maize.

Doehlert, D.C., M.S. McMullen, and J.J. Hammond. 2001. Genotypic and environmental effects on grain yield and quality of oat grown in North Dakota. Crop Sci. 41(4): 1066–1072. doi: 10.2135/cropsci2001.4141066x.

Fehr, W.R. 1991. Principles of Cultivar Development: Theory and Technique. 1st ed. Iowa State University.

Fiedler, J.D., E. Salsman, Y. Liu, M. Michalak de Jiménez, J.B. Hegstad, et al. 2017. Genome-Wide Association and Prediction of Grain and Semolina Quality Traits in Durum Wheat Breeding Populations. Plant Genome 10(3): 1–12. doi: 10.3835/plantgenome2017.05.0038.

Foreign Agricultural Service. 2020. Soybeans 2019 Export Highlights. USDA. https://www.fas.usda.gov/soybeans-2019-export-highlights#:~:text=In 2019%2C the value of,exports to other major markets.

Ganzel, B. 2020. Changing Cropping Patterns during the 1940s – Soybeans. https://livinghistoryfarm.org/farminginthe40s/crops_03.html (accessed 28 December 2020).

Garner, W.W.W.A.H.A., and H.A. Allard. 1930. Photoperiodic response of soybeans in relation to temperature and other environmental factors. J. Agric. Res. 41(10): 719–735.

Gillen, A.M. 2021. Uniform Soybean Tests Southern States 2020. Stoneville, Mississippi.

Gillen, A.M., and G.W. Shelton. 2020. Uniform Soybean Tests Southern States 2019. Stoneville, Mississippi.

GIPSA. 2006. Grain Inspection Handbook Book III Inspection Procedures.

Haaland, R.L. 1980. Food and Feed Grain Crops. In: Hoveland, C.S., editor, Crop Quality, Storage, and Utilization. American Society of Agronomy, Crop Science Society of America, Madison, Wisconsin. p. 1–34

Hartwig, E.E., and F.I. Collins. 1962. Evaluation of Density Classification as a Selection Technique on Breeding Soybeans for Protein or Oil 1 . Crop Sci. 2(2): 159–162. doi: 10.2135/cropsci1962.0011183x000200020024x.

Helms, T.C., C.R. Hurburgh, R.L. Lussenden, and D.A. Whited. 1990. Economic Analysis of

Increased Protein and Decreased Yield Due to Delayed Planting of Soybean. J. Prod. Agric. 3(3): 367–371. doi: 10.2134/jpa1990.0367.

Hepperly, P.R. 1978. Quality Losses in Phomopsis-Infected Soybean Seeds. Phytopathology 68(12): 1684. doi: 10.1094/phyto-68-1684.

Huber, S.C., K. Li, R. Nelson, A. Ulanov, C.M. DeMuro, et al. 2016. Canopy position has a profound effect on soybean seed composition. PeerJ 2016(9): 1–27. doi: 10.7717/peerj.2452.

Hurburgh, C.R., T.J. Brumm, J.M. Guinn, and R.A. Hartwig. 1990. Protein and oil patterns in U.S. and world soybean markets. J. Am. Oil Chem. Soc. 67(12): 966–973. doi: 10.1007/BF02541859.

Hymowitz, T. 2004. Speciation and Cytogenetics. In: Boerma, Roger and Spect, J., editor, Soybeans:Improvement, Production, and Uses. 3rd ed. American Society of Agronomy, Crop Society of America, and Soil Society of America, Madison, Wisconsin. p. 97–99

Immanuel, S.C., P. Nagarajan, K. Thiyagarajan, M. Bharathi, and R. Rabindran. 2011. Genetic parameters of variability, correlation and pathcoefficient studies for grain yield and other yield Attributes among rice blast disease resistant genotypes of rice (Oryza sativa L.). African J. Biotechnol. 10(17): 3322–3334. doi: 10.5897/AJB10.2575.

Kaya, Y., and M. Akcura. 2014. Effects of genotype and environment on grain yield and quality traits in bread wheat (T. aestivum L.). Food Sci. Technol. 34(2): 386–393. doi: 10.1590/fst.2014.0041.

Khazratkulova, S., R.C. Sharma, A. Amanov, Z. Ziyadullaev, O. Amanov, et al. 2015. Genotype

× environment interaction and stability of grain yield and selected quality traits in winter wheat in Central Asia. Turkish J. Agric. For. 39(6): 920–929. doi: 10.3906/tar-1501-24.

Kibar, H., and T. Öztürk. 2008. Physical and mechanical properties of soybean. Int. Agrophysics 22(3): 239–244.

Krishnan, H.B. 2001. Biochemistry and molecular biology of soybean seed storage proteins. J. New Seeds 2(3): 1–25. doi: 10.1300/J153v02n03_01.

De Leon, N., J.L. Jannink, J.W. Edwards, and S.M. Kaeppler. 2016. Introduction to a special issue on genotype by environment interaction. Crop Sci. 56(5): 2081–2089. doi: 10.2135/cropsci2016.07.0002in.

Li, Y.F., Y. Wu, N. Hernandez-Espinosa, and R.J. Peña. 2013. Heat and drought stress on durum wheat: Responses of genotypes, yield, and quality parameters. J. Cereal Sci. 57(3): 398–404. doi: 10.1016/j.jcs.2013.01.005.

Liu, J., J. Huang, H. Guo, L. Lan, H. Wang, et al. 2017. The conserved and unique genetic architecture of kernel size and weight in maize and rice. Plant Physiol. 175(2): 774–785. doi: 10.1104/pp.17.00708.

Liu, L., E. Prenger, J. Zhang, B. Little, M.A.R. Mian, et al. 2019. Impact of genotype, seed composition, agronomic trait, and environment on soybean test weight. J. Crop Improv. 33(6): 711–729. doi: 10.1080/15427528.2019.1659205.

Maestri, D.M., D.O. Labuckas, J.M. Meriles, A.L. Lamarque, J.A. Zygadlo, et al. 1998. Seed composition of soybean cultivars evaluated in different environmental regions. J. Sci. Food Agric. 77(4): 494–498. doi: 10.1002/(SICI)1097-0010(199808)77:4<494::AID-

JSFA69>3.0.CO;2-B.

McNeece, B.T., J.H. Gillenwater, Z. Li, and M.A.R. Mian. 2021. Assessment of soybean test weight among genotypes, environments, agronomic and seed compositional traits. Agron. J. (March): 1–11. doi: 10.1002/agj2.20665.

Meckel, L., D.B. Egli, R.E. Phillips, D. Radcliffe, and J.E. Leggett. 1984. Effect of Moisture Stress on Seed Growth in Soybeans 1 . Agron. J. 76(4): 647–650. doi: 10.2134/agronj1984.00021962007600040033x.

Medic, J., C. Atkinson, and C.R. Hurburgh. 2014. Current knowledge in soybean composition. J. Am. Oil Chem. Soc. 91(3): 363–384. doi: 10.1007/s11746-013-2407-9.

Mourtzinis, S., A.P. Gaspar, S.L. Naeve, and S.P. Conley. 2017. Planting date, maturity, and temperature effects on soybean seed yield and composition. Agron. J. 109(5): 2040–2049. doi: 10.2134/agronj2017.05.0247.

Naeve, S.L., and J. Miller-Garvin. 2019. United States Soybean Quality Annual Report.

NASS. 2021. Statistics by Subject Results. USDA. https://www.nass.usda.gov/Statistics_by_Subject/result.php?EAD2B220-BB40-3767-B0DE-B883430632CE&sector=CROPS&group=FIELD CROPS&comm=SOYBEANS (accessed 23 February 2021).

Office of the Law Revision Council of the US House of Representatives. 2020. [USC02] 7 USC Ch. 3: GRAIN STANDARDS. Off. Law Revis. Counc. U.S. House Represent. https://uscode.house.gov/view.xhtml?path=/prelim@title7/chapter3&edition=prelim (accessed 21 May 2020).

Panthee, D.R., and V.R. Pantalone. 2006. Registration of Soybean Germplasm Lines TN03–350 and TN04–5321 with Improved Protein Concentration and Quality. Crop Sci. 46(5): 2328–2329. doi: 10.2135/cropsci2005.11.0437.

Piper, E.L., and K.J. Boote. 1999. Temperature and Cultivar Effects on Soybean Seed Oil and Protein Concentrations. J. Am. Oil Chem. Soc. 76(10): 1233–1241.

Pixley, K. V., and K.J. Frey. 1991. Inheritance of Test Weight and Its Relationship with Grain Yield of Oat. Crop Sci. 31(1): 36–40. doi: 10.2135/cropsci1991.0011183x003100010008x.

Pomeranz, Y., G.E. Hall, Z. Czuchajowska, and F.S. LAI. 1986. Test Weight, Hardness, and Breakage Susceptibility of Yellow Dent Corn Hybrids. Cereal Chem. 63(4): 349–351.

Prasanth, P.S. 2007. Purple seed stain of soybean - its incidence , effect on seed quality and integrated management. 60(4): 482–488.

Robinson, A.P., S.P. Conley, J.J. Volenec, and J.B. Santini. 2009. Analysis of high yielding, early-planted soybean in Indiana. Agron. J. 101(1): 131–139. doi: 10.2134/agronj2008.0014x.

Roy, K.W. 1976. Purple Seed Stain of Soybeans. Phytopathology 66(9): 1045. doi: 10.1094/phyto-66-1045.

SAS Institute. 2015. Base SAS 9.4 Procedures Guide Statistical Procedures. Second. Cary, NC.

Sissons, M., D. Pleming, J.D. Taylor, L. Emebiri, and N.C. Collins. 2018. Effects of heat exposure from late sowing on the agronomic and technological quality of tetraploid wheat: Cereal Chem. 95(2): 274–287. doi: 10.1002/cche.10027.

Smith, R.W. 1940. Circular of National Bureau of Standards C425 Legal Weights per Bushel for

Various Commodities. Washington, D C.

Sun, X.-Y., A.E. Ke, W. Ae, Y. Zhao, F.-M. Kong, et al. 2008. QTL analysis of kernel shape and weight using recombinant inbred lines in wheat. Euphytica 165: 615–624. doi: 10.1007/s10681-008-9794-2.

U.S. Soybean Export Council. 2005. U.S. Soy : International Buyers ’ Guide. St.Louis, MO.

United States Department of Agriculture. 1953. Circular No.921:The Test Weight Per Bushel of Grain: Methods of Use and Calibration of the Apparatus. Washington, D C.

United States Department of Agriculture Agricultural Marketing Service Federal Grain Inspection Service. 2007. US Standards.

United States Department of Agriculture Agricultural Marketing Service Federal Grain Inspection Service. 2020. Grain Inspection Handbook.

United States Department of Agriculture Farm Service Agency. 2019. 2019 Crop Year Premium & Discounts and Additional Discounts for Corn , Grain Sorghum and Soybeans. https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/Price-Support/pdf/2019/2019_corn_grain_sorghum_soybeans.pdf.

United States Department of Agriculture Marketing and Regulatory Programs Agricultural Marketing Service Federal Grain Inspection Service. 2020. Grain Inspection Handbook Book II Grain Grading Procedures. Washington, D C.

Vázquez-Carrillo, M.G., I. Rojas-Martínez, D. Santiago-Ramos, J.L. Arellano-Vázquez, A. Espinosa-Calderón, et al. 2016. Stability Analysis of Yield and Grain Quality Traits for the Nixtamalization Process of Maize Genotypes Cultivated in the Central High Valleys of

Mexico. J. Crop Sci. 56(6): 3090–3099. doi: 10.2135/cropsci2015.09.0558.

Visher, S.S. 1940. Weather Influences on Crop Yields. Econ. Geogr. 16(4): 437–443. https://www.jstor.org/stable/140953.

Visscher, P.M., W.G. Hill, and N.R. Wray. 2008. Heritability in the genomics era - Concepts and misconceptions. Nat. Rev. Genet. 9(4): 255–266. doi: 10.1038/nrg2322.

Wills, K. 2013. Where do all these soybeans go? - MSU Extension. Michigan State Ext. https://www.canr.msu.edu/news/where_do_all_these_soybeans_go (accessed 5 February 2021).

Wood, C.W., L.J. Krutz, L. Falconer, H.C. Pringle, T. Irby, et al. 2016. Soybean Grade Requirements and Discount Schedules.

Zhe, Y., J.G. Lauer, R. Borges, and N. de Leon. 2010. Effects of genotype × environment interaction on agronomic traits in soybean. Crop Sci. 50(2): 696–702. doi: 10.2135/cropsci2008.12.0742.

CHAPTER 2

INVESTIGATING TEST WEIGHT INSTRUMENTS FOR SOYBEAN BREEDING

Introduction

Soybean test weight (TW) is a characteristic that has become of great interest to both farmers and breeders. Test weight measures unit weight per unit volume (bulk density) and is used by grain elevators to convert the weight displayed on the scale into the number of bushels contained in a load (Haaland, 1980; Davidson, 2018a). For soybean, the U.S legal standard weight is 60 lbs per Winchester bushel (75.7 kg hL^{-1}) also known as the United States bushel (35.24 liters) (United States Department of Agriculture, 1953; Canadian Grain Commission, 2019). TW as a measure of bulk density however, it is the weight of a certain volume of grain that is required to fill a Winchester bushel, for soybean it is 35.24 liters. The legal weight per bushel is the amount number of lbs of grain that is required for a bushel with no regard for volume and is the basis for which grain is typically bought and sold (; USDA, 1953). This standard of legal TW also varied by state, it was 58 lbs (73.3 kg hL^{-1})in some states and 60 lbs (75.7 kg hL^{-1}) in others (Smith, 1940). For grading standards, Grade 1 soybean have a TW of 56 lbs (70.8 kg hL^{-1}), Grade 2 is 54 lbs (68.4 kg hL^{-1}), Grade 3 is 52 lbs (65.9 kg hL^{-1}), and Grade 4 is 49 lbs (62.3 kg hL^{-1}) (Canadian Grain Commission, 2005; U.S. Soybean Export Council, 2005). However as of 2007 it is no longer used as a grading factor, but still used for guidelines (GIPSA, 2006). When the TW measurement falls below 54 lbs (68 kg hL^{-1}) (Canadian Grain Commission, 2005), the grower receives a discounted payment. This dockage is due to the limited filling capacity of the equipment. Both storage bins and extraction equipment are limited by volume, meaning that they can hold less mass with a lower TW than a higher one (Davidson, 2018b). In 2018, the average TW measurement in the US was 58 lbs (73.3 kg hL^{-1}) (Canadian

Grain Commission, 2005; Naeve and Miller-Garvin, 2019). However, in certain areas in the southern regions of production, TWs have declined further. The reason for this decline is unknown. Growers have approached breeders to address the issue and determine if TW values could be improved through breeding.

TW is likely a combination of multiple traits (seed size and composition) (Liu et al., 2019; McNeece et al., 2021) and the effect of the environment, which implies that it is a quantitative trait. Through time, breeders have focused on yield and primarily the main seed components such as oil and protein. Therefore, there is a large knowledge gap as to which traits have the most influence on the overall TW value. Since TW is a measure of the seed bulk density, it is influenced by seed composition, the overall shape, size, and weight of the seed (Liu et al., 2019; McNeece et al., 2021). Recent studies reported that seed size, oil, and moisture are negatively related to TW, while protein has a positive correlation (Liu et al., 2019; McNeece et al., 2021).

In any breeding program, the ability to measure a trait of interest is critical. Measurements must be reliable and affordable since screening multiple populations requires significant resources. For TW, the volumetric instrument is considered the gold standard as it was used to develop the measurement. It does not give the user temperature or moisture levels of the sample (Boerner, 1916). The instrument consists of multiple components including a quart kettle, a scale, a filling hopper, an overflow pan, and a stroker (Lee, 2013). The total cost of its components could range from ~ $908 to $2209 depending on the scale purchased (Seedburo Equipment, 2021).

Electronic machines that include more information such as moisture and temperature, have been introduced. Two well-known TW grain analyzer brands are Perten (Perkin Elmer, Waltham, MA) and DICKEY-john (DICKEY-john corporation, Auburn, IL). The Mini-GAC Plus (GAC) (DICKEY-john Corporation) is a portable grain analyzer that allows for samples to be measured in the field. It measures TW and moisture using propriety an algorithm and a set of internal scales (DICKEY-john Technical Support, 2020, Personal Comm). It weighs 2 lbs and costs about $500, making it a cheaper option to measure TW (Rural King, 2020). The results are generated in seconds. The drawback of using this device is it must be recalibrated after each sample measured (DICKEY-john Corporation, 2017). The Perten Aquamatic 5200 (Perten) (Perkin Elmer) also measures TW, moisture, and temperature for a sample in seconds. It uses a set of internal scales and the unified grain moisture algorithm, developed by the USDA, to measure moisture and TW (Perten Instruments, 2013). Unlike the GAC, the Perten does not need to be recalibrated after each sample. One possible draw back however is that the Perten is not a portable machine. It weighs 40 lbs (Flaman Group of Companies, 2021) and costs $5800 (Phillip Crim, 2020, Personal Communication).

In this study, three instruments were examined to determine the efficiency, reproducibility and similarity for research and breeding programs: a GAC, a Perten, and a volumetric instrument. In an agronomic research setting, TW can be measured using either a Perten, GAC, or volumetric instrument. The volumetric instrument is considered the gold standard for measuring TW and is still used in some grain elevators to measure TW. The purpose is to understand the relationship between these three instruments and determine which one would be the best to use for a breeding program

Materials and Methods

Southern Uniform Test

The Uniform Soybean Tests - Southern States (Uniform) is a set of soybean yield tests ranging from maturity group (MG) IV to VIII in 12 states (Gillen and Shelton, 2020; Gillen, 2021). Each MG is supplied with its own set of advanced public breeding lines and a set of commercial check cultivars. In 2019 and 2020, the number of lines or entries within a test ranged from 13 to 33. The samples from Tallassee AL were used for this study. The Uniform VI, VII, and VIII were grown at the E.V. Smith Research Center (EVS) at Tallassee, Al. (32.4967° N, 85.8905° W) on a Kb-Kalmia (fine-loamy over sandy siliceous, semiactive thermic Typic Hapludult Kalmia). Each entry was planted in four-row plots with 36 inch row spacing.

For the Tallassee, AL, location in 2019, Uniform MG IV-Late was planted on May 8, Uniform MG V was planted on May 21, Uniform MG VI on June 3 and Uniform MG VII on June 17.. In 2020, the Uniform MG V was planted on May 1, Uniform MG VI on May 15, and the Uniform MG VII on June 2. In 2019, the Uniform MGs IV and V were harvested , with an Almaco SPC 40 on November 11. Uniform MG VI was harvested on November 21 and Uniform MG VII and VIII were harvested on November 18 (Gillen and Shelton, 2020; Gillen, 2021). The seed sample was cleaned with a Seedburo clipper seed cleaner prior to TW measurements. The cleaner removes foreign matter, debris, broken or low weight seed and other matter that may skew a TW measurement. In 2020, all trials were harvested with an Almaco R1 rotary combine, which allowed for a cleaner sample and eliminated the need for additional cleaning. In 2020, the

Uniform MG VI and VII,were harvested on November 2.The Uniform MG VIII was harvested on November 10.

In addition to the Uniform Tests, two individual Harvest Trials were conducted (MG VI and VII) in Tallassee, Alabama in 2020. The trials are a split plot design with entry being the main effect and harvest date the split; each have 25 entries selected for their seed composition with three replications per harvest date. Planting occurred on June 2 and grown under irrigation and in accordance with the Alabama Extension guidelines for soybean production (Nichols, 2021). Maturity group VI was harvested on October 23 and MG VII on November 2. For this study, only the first harvest date TWs were recorded.

Measurement Methods

Soybean seed samples grown at, Tallassee, AL, were allowed to equilibrate to room temperature for a minimum of three days to dry down in both years. Three separate TW grain analyzers: A Seedburo volumetric instrument, a Perten (Perkin Elmer), and a handheld GAC (DICKEY John Corporation) were used on three separate plot subsamples for a total of 9 measurements. For the Perten, the sample was placed into the chamber and filled to the top of the wire crosshairs. The soybean setting was selected, and the measurement was recorded. For the GAC, the soybean setting was selected and filled to the appropriate marking. The seed was then allowed to fill the device and a striker removed excess seed. The measurement was then recorded. The volumetric instrument consists of multiple components; a striker, filling hopper, quart kettle, scale, and an overflow pan (Lee, 2013). The sample was placed in the filling hopper and the stopper was removed allowing the sample to fall into the ½ liter cup. Once the cup was full, the sample is struck by the striker to remove excess soybean. The sample is then placed on a scale that gives the weight in grams, the weight is converted into the Winchester Bushel TW using the Canadian Grain Commission TW conversion chart (Canadian Grain Commission, 2005).

Timing the Instruments

Each machine was timed in order to estimate how long it would take a breeding program to process one thousand samples. Each sample was measured 10 times and the amount of time it took to measure the sample was recorded. The GAC was timed from calibration up to the point the measurements were displayed. The Perten was timed from the point of loading the sample into the machine until the measurements were displayed. The volumetric instrument was recorded from the point of loading the sample into the filling hopper until the measurements were displayed on the scale. The average times for each instrument were multiplied by 1000 and converted into the time it would take in hours.

Statistical analysis

All measured traits were analyzed with SAS software Version 9.4._TS1M2 for Windows (SAS Institute, 2002-2012).The mean of the three subsample measurements for each plot from Uniform Test conducted in Tallassee, AL, and the Harvest Trial were calculated and used to represent the experimental unit in the statistical analysis for a total of 517 observations. PROC REG and PROC CORR, procedures were run to obtain correlations and regression lines between the three instruments. The PROC REG command was used to examine the relationship between the three TW instruments and generate regression equations. The PROC CORR (Pearson's Coefficient) was used to analyze the correlations between TW and moisture. A two tailed t-test was also used to analyze the efficiency of the instruments using the times of the ten replications of the sample measured. This was conducted using PROC TTEST.

Results and Discussion

Evaluation of the Measurement Instruments

The objective of this study was to compare and contrast three instruments in order to determine which one is best suited for any research-breeding program. In a research agronomic setting, TW's can be measured using either a Perten, GAC or volumetric instrument. Breeding programs normally process hundreds or thousands of samples and thus need an efficient, reliable device. The average time to process one sample for the Volumetric, Perten, and GAC was found to be approximately 22, 24, and 32 seconds, respectively. These values were all found to be significantly different from each other by the t test. These values were extrapolated to estimate how long it would take to process one thousand samples; ~ 6.11, 6.67, and 8.88 hours for the Volumetric, Perten, and GAC, respectively. As efficiency is important in a research program and labor costs are always occurring, the Perten would be the most time efficient when both soybean seed moisture and temperature data are needed. Also, in experiments that are examining different soybean genotypes from different locations it is vital to standardize it to 13% moisture. The equation is TWp= 4.955 + 0.200* Moisture + 0.898 * TWO (Liu et al., 2019). For this equation to be used the moisture value for the sample must be known, therefore making the Perten the best option for a research across different locations and genotypes based off these results.

In order to evaluate the instruments, accuracy was considered. A regression was performed between the machines to determine their similarity. Since the volumetric is the standard, the Perten and GAC results were each compared to the volumetric results. Across eleven experiments the volumetric instrument averaged 71.9 kg hL^{-1} and the average seed size was 15.0g. Moisture and temperature were recorded on the Perten and the GAC. The comparison of the Perten to the Volumetric instrument had the highest R^2 value (0.934) (Figure 1). The volumetric and the GAC R^2 value was 0.845 (Figure 2) and the comparison of the Perten to the GAC was 0.904 (Figure 3). These results indicate that the Perten gives a more accurate measure than the mini-GAC when compared to the volumetric. The Perten is self-contained and stationary whereas the GAC is a portable handheld device and may explain why the former is more accurate. Comparing both electronic devices resulted in a R^2 of 0.934, this indicates that any of the machines are reliable in providing an appropriate TW value. For measuring copious numbers of samples for breeding, either instrument is useful as long as all the samples are measured on that device. Breeders typically want to know how a genotype varies from another, better or worse, and not necessarily the most exact number. In addition, the regression equations can be used to convert values of one instrument to another (Table 1). For measuring copious numbers of samples for breeding, either instrument is useful as long as all the samples are measured on that device. Breeders typically want to know how a genotype varies from another, better or worse, and not necessarily the most exact number This would allow researchers conducting a TW study with multiple cooperators who have access to one measurement instrument, such as a Perten, but not the other , such as a GAC, to use the instrument and participate in the study without having to purchase another instrument. Therefore, based on the objective of the TW measurement, any of the instruments would be suitable.

It should be noted that the DICKEY- John Corporation makes a variety of electronic instruments to measure TW, moisture, and temperature. The mini-GAC was specifically chosen since it is a cheaper model, which allows for researchers on a tighter budget the ability to record TW. The regression equation presented in Table 1 would allow a researcher to convert TW measured with a mini-GAC to get a Perten equivalent. This is useful information when different locations are using different TW instruments.

Moisture Correlations to Test Weight

The TW from 2019-2020 ranged from 46.9 lbs (59.6 kg hL^{-1}) to 60.9 lbs (76.7 kg hL^{-1}), and moisture ranged from 7.3 to 16.3. Since the electronic devices allow both moisture and temperature to be recorded, the relationship with TW and moisture was estimated. This was over all MG Our results indicate a significant negative correlation between seed moisture and TW in both the Perten and Mini-GAC (Table 1). This is in agreement with Liu et al., (2019) who also reported this relationship. This has also been described in corn, as corn moisture increased from 10 to 30% moisture, TW decreased (Nelson, 1980). In wheat, moisture increases from 3 to 8% caused TW to rise slightly, but as it got closer to 24%, TW decreased (Nelson, 1980). There is limited information reported on soybean TW's (Liu et al., 2019). **Conclusion**

In conclusion, soybean TWs measured on the volumetric instrument are considered the best and most accurate measurements. The Perten Aquamatic 5200 provided a higher correlation with the volumetric compared to a mini-GAC. However, depending on research objective, any of these instruments is adequate in terms of data quality. For measurements that require TWs with both moisture and temperature, the Perten delivers data more efficiently; that is, in a shorter time. This would be useful for studies that would be comparing TWs across different genotypes and environments due to their need for standardization (Liu et al., 2019). Future experiments need to be performed to determine how other seed quality parameters influence sample measurements.

References

Boerner, E.. 1916. Bulletin No. 472:Improved Apparatus for Determining the Test Weight of Grain, with a Standard Method of Making the Test. Wa.

Canadian Grain Commission. 2005. Test Weight Conversion Chart.

Canadian Grain Commission. 2019. Test weight for Canadian grains. Can. Gov. https://www.grainscanada.gc.ca/en/grain-quality/grain-grading/grading-factors/test-weight-grain.html (accessed 21 February 2021).

Davidson, D. 2018a. Understanding Test Weight | ILSoyAdvisor. Illinois Soybean Assoc. https://www.ilsoyadvisor.com/on-farm/ilsoyadvisor/understanding-test-weight (accessed 11 January 2021).

Davidson, D. 2018b. Test Weight Matters in 2019. Illinois Soybean Assoc. https://www.ilsoyadvisor.com/on-farm/ilsoyadvisor/test-weight-matters-2019 (accessed 29 May 2020).

DICKEY-john Corporation. 2017. Agricultural Product Catalog. : 46. http://www.dickey-john.com/_media/dickey-john_product catalog_web_2017.pdf (accessed 3 March 2020).

Flaman Group of Companies. 2021. Perten AM 5200 Grain Moisture Meter. https://www.flamangrainsystems.com/products/aquamatic-5200-grain-moisture-meter-118#.YNOhGehKhPY (accessed 23 June 2021).

Gillen, A.M. 2021. Uniform Soybean Tests Southern States 2020. Stoneville, Mississippi.

Gillen, A.M., and G.W. Shelton. 2020. Uniform Soybean Tests Southern States 2019. Stoneville, Mississippi.

GIPSA. 2006. Grain Inspection Handbook Book III Inspection Procedures.

Haaland, R.L. 1980. Food and Feed Grain Crops. In: Hoveland, C.S., editor, Crop Quality, Storage, and Utilization. American Society of Agronomy, Crop Science Society of America, Madison, Wisconsin. p. 1–34

Lee, G.D. 2013. Determining Reference Test Weight per Bushel Value of Grains.

Liu, L., E. Prenger, J. Zhang, B. Little, M.A.R. Mian, et al. 2019. Impact of genotype, seed composition, agronomic trait, and environment on soybean test weight. J. Crop Improv. 33(6): 711–729. doi: 10.1080/15427528.2019.1659205.

McNeece, B.T., J.H. Gillenwater, Z. Li, and M.A.R. Mian. 2021. Assessment of soybean test weight among genotypes, environments, agronomic and seed compositional traits. Agron. J. (March): 1–11. doi: 10.1002/agj2.20665.

Naeve, S.L., and J. Miller-Garvin. 2019. United States Soybean Quality Annual Report.

Nelson, S.O. 1980. Moisture-Dependent Kernel- and Bulk-Density Relationships for Wheat and Corn.

Nichols, K. 2021. Irrigated Soybean Enterprise Budget - Alabama Cooperative Extension System. Auburn Univ. Ext. https://www.aces.edu/blog/topics/farm-management/irrigated-soybean-enterprise-budget/ (accessed 28 May 2021).

Perten Instruments. 2013. Aquamatic 5200 (-A).

Rural King. 2020. Dickey John Mini GAC PLUS Grain Moisture Tester - MINIGAC1P. Rural King. https://www.ruralking.com/dickey-john-mini-gac-plus-grain-moisture-tester-minigac1p (accessed 2 December 2020).

Seedburo Equipment. 2021. Grain Inspection and Grading - Seedburo Equipment Company. Seedboro Equip. Co. https://seedburo.com/collections/grain-inspection-and-grading?tab=products&page=4 (accessed 25 June 2021).

Smith, R.W. 1940. Circular of National Bureau of Standards C425 Legal Weights per Bushel for Various Commodities. Washington, D C.

U.S. Soybean Export Council. 2005. U.S. Soy : International Buyers ' Guide. St.Louis, MO.

United States Department of Agriculture. 1953. Circular No.921:The Test Weight Per Bushel of Grain: Methods of Use and Calibration of the Apparatus. Washington, D C.

CHAPTER 3

EXAMINING SOYBEAN TEST WEIGHT IN RELATION TO GENOTYPIC, ENVIRONMENTAL, AND GXE INTERACTIONS

Introduction

In row crops grown for seed, a test weight (TW) is measured in order to rate quality. It is a bulk density measure, unit weight per unit volume, used at the selling point in order to determine the number of bushels in a load (Haaland, 1980; Davidson, 2018a). The standard soybean (*Glycine max* L.) TW according to the U.S. law is 60 lb bu^{-1} or 75.7 kg hL^{-1} (Bern and

Brumm, 2009). TW as a measure of bulk density however, it is the weight of a certain volume of grain that is required to fill a Winchester bushel, for soybean it is 35.24 liters. The legal weight per bushel is the amount number of lbs of grain that is required for a bushel with no regard for volume and is the basis for which grain is typically bought and sold (USDA, 1953). The legal TW per bushel varied by state (Smith, 1940). TW as a measure of bulk density was originally used for grading soybean, but is now used more as a guideline (GIPSA, 2006). Historically the TW guidelines for Grades 1, 2, 3, and 4 have been 69 kg hL^{-1}, 67 kg hL^{-1}, 64 kg hL^{-1}, and 61 kg hL^{-1} respectively (U.S. Soybean Export Council, 2005). When the TW measurement falls below 67 kg hL^{-1} the grower is docked (Wood et al., 2016; Davidson, 2018b). Storage bins and extraction equipment are limited by volume, meaning that they hold less mass with a lower TW than a higher one (Davidson, 2018a). Test weight can also cause an increase in transportation costs. Soybean with low TWs occupy the same space but have a lower mass than soybean with high TW. This may cause a need for more trucks to be used to transport the same amount of mass (McNeece et al., 2021).

There has been a growing concern with soybean producers that the average TW is falling below the 67 kg hL^{-1}, resulting in unexpected discounts and the inability to actually achieve a 75 kg hL^{-1} (Davidson, 2018b). In the Midwest, TW measurements typically arrive with an average weight between 70.8 kg hL^{-1} and 73 kg hL^{-1} (Davidson, 2018b). The average U.S. TW in 2018 was 73.1 kg hL^{-1}(Naeve and Miller-Garvin, 2019). However, in certain soybean growing areas of the U.S., mostly in the southern region, TWs have declined further.

The knowledge of TW is limited in soybean, but seed composition, weight and size play a part in the final TW value. Recent work suggests that as seed size increases, TW decreases (Liu et al., 2019). In addition to seed size, increases in moisture decrease TW (Liu et al., 2019). Oil and protein make up a majority of the seed composition and can vary by the region where it is grown. High seed densities correlate with high protein content, while lower densities correlate with high oil content (Hartwig and Collins, 1962). One recent study found that protein has a positive correlation with TW, while oil and TW have a negative correlation (Liu et al., 2019). This was confirmed in the results of McNeece et al., (2021) in which protein content was positively correlated to TW, while oil content and seed index (weight of 100 seeds) were negatively correlated to TW.

The environment of different regions can affect the seed composition. Varieties grown in Northern and Western states have 1.5-2.0% less protein and 0.2-0.5% more oil and have the potential to produce a higher oil content than varieties grown in the Southern states. (Hurburgh et al., 1990). These differences could be due to differences in genotype and the environment (Piper and Boote, 1999). As regional environmental differences affect seed composition, for example, altitude is positively correlated with protein and oil; latitude and precipitation are negatively correlated with protein. Temperature and precipitation are negatively correlated with oil (Maestri et al., 1998). The position of the seed pod on the plant can also influence oil and protein content in the seed (Huber et al., 2016).

Environmental factors that affect protein and oil such as biotic and abiotic stresses also impact TW (Roy, 1976; Hepperly, 1978; Prasanth, 2007). Genotype x environment interactions (GxE) has been shown to reduce response to selection (Fehr, 1991)and were highly significant to wheat (Li et al., 2013; Khazratkulova et al., 2015), maize (Vázquez-Carrillo et al., 2016), oats (Doehlert et al., 2001), and sorghum TWs (Chiremba et al., 2011). In soybean, signifiant GxE interactions have been reported however the heritability estimates for those populations were greater than 50%, indicating, that the TW could benefit from selection (Liu et al., 2019; McNeece et al., 2021).

Breeders need a better understanding of the influence of factors that comprise the TW value in order to make progress in improving modern soybean cultivars. Therefore, the objective of this study is to determine the role GxE plays on TW across a range of maturity groups and investigate the influence of seed composition traits on overall TW values.

Materials and Methods

Uniform Test Planting and Harvesting

The Uniform Soybean Tests - Southern States (Uniform) is a set of tests ranging from maturity group (MG) IV to VIII in 12 states (Gillen and Shelton, 2020; Gillen, 2021). Each MG is supplied with its own set of advanced public breeding lines and a set of commercial check cultivars and is considered an individual test. In 2019 and 2020, the number of lines or entries within a test ranged from 13 to 33. The design of each trial was a completely randomized block design with 3 replications. The plot size, soil type, and other agronomic factors may be found in the annual reports for 2019 and 2020 (Gillen and Shelton, 2020; Gillen, 2021). The data being presented from the individual trials is listed in Table 3. The MG V, VI, and VII were used in this study in order to have a more clear assessment of TW for Alabama.

Collection of Agronomic and Seed Characteristic Data

Various agronomic and seed characteristics were measured to examine their potential effect on TW. These characteristics include yield, seed size, oil, protein, and plant height. Plant height measurements were taken in inches about 2-3 weeks before harvest in 2019 and 2020. The measurements were averaged and measured from the ground to the top extremity when the plant reaches maturity (Gillen and Shelton, 2020; Gillen, 2021). One hundred random seeds were taken from each sample (plot) to create a subsample. The subsample was measured in grams to estimate the overall seed size (100 seed weight) of each plot (Gillen and Shelton, 2020; Gillen, 2021). Test weights were measured by a mini-GAC Plus, (GAC) (DICKEY-john corporations, Auburn, IL). Oil and protein subsamples were taken from each entry and replication in the trial in 2019 and 2020. The samples were ~50 grams. In 2020, tests grown at Kinston, NC, and Plymouth, NC, did not have oil and protein data from all replications and therefore a single bulk sample was taken per entry and used for analysis (Gillen, 2021). They were sent to the USDA-ARS Bio-Oils Research Unit in Peoria, IL to analyze the percentage of oil and protein in each sample using near infrared transmittance (NIT) (Gillen and Shelton, 2020; Gillen, 2021). Yield was estimated and converted into bushels per acre (Gillen and Shelton, 2020; Gillen, 2021).

Locations and genotypes varied by year (Table 3). Each individual cooperator measured the same traits and provided the USDA and Auburn with the raw data. Planting and harvest dates, and production practices depended on the location of the cooperators as reported in annual report of the Uniform Tests (Gillen and Shelton, 2020; Gillen, 2021).

Statistical Analysis

All TW values were converted into kg hL^{-1} and standardized to 13% moisture. Conversion of TW values into kg hL^{-1} was done by multiplying the TW values in lbs bu^{-1} by 1.287 according to the USDA standards (GIPSA, 2006). Normalization of TW data is necessary due to different genotypes increasing in seed size and TW decreasing 0.20 to 0.25 kg hL^{-1} as moisture percentage increased (Liu et al., 2019). This was achieved by applying the formula TWp= 4.955+ 0.200* generated by Liu et al. (2019).

All data was analyzed using SAS software Version 9.4._TS1M2 for Windows (SAS Institute, 2002-2012) (SAS Institute, 2015). Years were analyzed independently due to different genotypes and locations in each year. PROC GLM was used to calculate the least square means (LS means). A series of ANOVAs were conducted to analyze the TW value in individual years. First, an ANOVA was conducted for TW in each year using a model where with MG tests was a fixed effect with location and rep(location) as random effects. This calculated the LS means for each MG.

1. MG: TW= MG random= location location(rep).
2. Separate analysis for each MG: TW= variety variety*location random= location location(rep).

For broad sense heritability, the mean squares of each MG in each year with the equation $H^2 = \sigma^2 g / \sigma^2 p$. When the fixed effects of the locations and genotypes, or their interactions were significant the least square means post-hoc were performed to compare means. PROC CORR determined Pearson's coefficients between seed composition and agronomic traits with TW based on the means of each experiment.

Results

In both 2019 and 2020, there is significant location effect (E) followed by the genotype and to a lesser extent the GxE interactions (Table 4) The GxE is smaller than both the location and genotype effects, indicating that while GxE is significant it is likely not as important for TW as the location effect (E) and genotype.

Comparison of Soybean Test Weights Means for Maturity Groups V, VI, and VII

In 2019 and 2020, for MGs V, VI, and VII (Table 5), none of the MG means for TW reached 75.7 kg hL^{-1}. However, none of the MGs in either year fell within the discount range (68.4 kg hL^{-1}). The means varied with by year with MG VII, with the highest TW mean of 73.3, being statistically different from MG V and VI, TW means of 71.9 and 71.8 respectively in 2019. In 2020, MG V and VI were not statistically different from each other, with TW means of 72.8 and 73.2 respectively.

Comparison of Test Weight for all Locations for each Maturity Groups

Not a single overall TW mean for any location achieved 75.7 kg hL^{-1} in either year (Table 6), but a few locations in each year came close. In 2019, Portageville, MO, (MG V) had an average mean of 74.2, and Florence, SC, (MGs VI and VII) had an average mean of 74.6 and 74.2, respectively.(Table 6) According to the ranges there were some varieties in 2019, Portageville, MO for MG V, Florence, SC for MG VI, and Athens, GA (B), Florence, SC, and Tallassee, AL for MG VII achieved or exceeded 75.7 kg hL^{-1}(Table 7). In 2020, Manhattan, KS, (MG V) had an average mean of 74.5, and Tallassee, AL, (MGs VI and VII) had an average mean of 74.5 and 74.3, respectively. There were some varieties in the range for 2020 that also achieved or exceeded 75.7 kg hL $^{-1.}$None of the location TW means fell within the discount range of 68.4 kg hL^{-1} in either year, but there were some individual varieties in the ranges of both years that fell within discount range.

Comparison of Test Weight for Individual Varieties

In 2019, three MG V varieties reached 75 kg hL^{-1} at Portageville, MO, (Table 8) while MG VI varieties AG64X8 RR2X, CZ6316LL, and G15-3606R2 reached the target value and 7 varieties exceeded it (Table 9). In MG 7, only a single variety to reach the target value in 3 locations, while 5 varieties that made 75 kg hL-1 in at least one location (Table 10).

In 2020, for MG V (Table 11), variety R14-1422 achieved 75 kg hL^{-1} at Belle Mina, AL, and varieties R13-14635RR, R15-1587, S16-9090C, TN16-5024, and V16-0709PR reached 75 kg hL^{-1} at Manhattan, KS. For MG VI (Table 12), varieties G15-1038R2 and N10-7412 achieved 75 kg hL^{-1} at Tallassee, AL. The variety G15-1811R2 exceeded 75 kg hL^{-1} at Tallassee, AL, while G16-8779, N11-12528, and N16-10756 achieved or exceeded 75 kg hL^{-1} at Kinston, NC, and Tallassee, AL. For the MG VII, varieties AG74X8 RR2X, AGS-738RR, N16-10518, N16-10740, and N16-9134 achieved 75 kg hL^{-1} at Tallassee, AL. The variety N94-7441 achieved 75 kg hL^{-1} at Plains, GA, and exceeded it at Tallassee, AL (Table 13).

Broad Sense Heritability and Agronomic and Seed Trait Correlations

Broad sense heritability for TW is moderate to high in 2019, with 0.56, 0.88, and 0.65 estimates for MGs V, VI, and VII, of the Southern Uniform Test respectively. In 2020, broad sense heritability for TW in the tests for MG VI was high and MG VII was still moderate, but MG V was low with 0.36 (Table 14).

In 2019, the trials that included MG V, were examined and found that all traits except yield have a negative correlation with TW (Table 15). In Knoxville, TN, Portageville, MO, and Tallassee, AL,: seed size and oil are negatively correlated with TW. In Pittsburg, KS, there was no significant correlation between the traits observed and TW. For the trials that involved MG VI for 2019, yield, height, and oil had negative correlations with TW while protein had a positive correlation. In Plains, GA, there were significant negative correlations with seed size and oil for TW. At Florence, SC, and Tallassee, AL, there were no significant correlations between the examined traits and TW. For trials that involved MG VII in 2019, yield, and oil, were negatively correlated while protein was positively correlated with TW. At Athens, GA (A) yield and oil were negatively correlated with TW. Athens, GA (B) and Plains, GA had no significant correlations between the observed traits and TW. At Florence, SC, oil was negatively correlated with TW. At Tallassee, AL, seed size and oil were negatively correlated with TW, and protein was positively correlated.

In 2020, seed size, and oil, were negatively correlated with TW and plant height was positively correlated with TW. Protein and yield were not significantly correlated with TW (Table16). When considering the individual locations that grew the tests with MG V in 2020, there were no significant correlations. For the tests with MG VI in 2020, the correlation between yield and protein with TW were not significant. Tallassee, AL, was the only individual location with a significant correlation, which was seed size negatively correlated to TW. For the tests with MG VII in 2020, total plant height and seed size are negatively correlated with TW while protein was positively correlated. Individually Athens, GA, Plains, GA, and Plymouth, NC, were all negatively correlated with seed size. Plymouth, NC was also negatively correlated with yield for TW.

Discussion

Test Weight Value

Based on the means of location and individual varieties, in the southern states, the TW value may be declining (Table 5). While most of the varieties did not reach 75.7 kg hL^{-1}, most did not fall within the discount range. Several varieties were within range for Grade 1 soybean. This begs the question as to whether the 75.7 kg hL^{-1} value is an appropriate expectation for soybean producers. With limited documented evidence on soybean TW values, has this 75.7 kg

hL^{-1} value ever been consistently achieved? Growers have voiced concern about the decline in TW but perhaps it is the inability to reach the target that is why they are troubled.

Heritability of Test Weight

Based on these results and in accordance with Liu et al., (2019) and McNeece et al., (2021) TW is a trait that can be bred. The broad sense heritability values being greater than 50% in both years and MGs, so simply selecting lines with a higher TW should be effective. Studies on TWs in other crops determined the same, with moderate to high broad sense heritability, in oat (Pixley and Frey, 1991; Doehlert et al., 2001), wheat (Sun et al., 2008; Fiedler et al., 2017), maize (Ding et al., 2011; Liu et al., 2017), and rice (Immanuel et al., 2011). However, as TW is not a current selection trait, how is selecting for individual seed composition traits impacting that value?

Correlations between Agronomic and Seed Traits with Test Weight

Oil, and seed size, were negatively correlated with TW in both years. Height, yield and protein had inconsistencies in MGs and in years. These results are consistent with the inconsistencies across the experiments performed by Liu et al, (2019) and the negative correlations for oil and seed size. Protein was positively correlated with TW and makes sense since is negatively correlated with protein and with TW.

For the MGs there was not anything that was consistent to an individual MG in both years. Across all trials, yield, plant height, seed size, and oil have a significant negative correlation with TW. These results could be due to the production environments and suggests that Southern breeders are breeding for higher oil content and inadvertently reducing TW (Hurburgh et al., 1990). This is challenging in that breeders primary objective is in most cases yield. If this suffers, material does not advance in the breeding pipeline. Strategies to overcome this negative association should be investigated.

This study highlights the moderate genotype and large environment effect on TWs with GxE adding a small but still significant effect. Similar results supporting a large environmental effects on TW have been seen in soybean (Liu et al., 2019; McNeece et al., 2021) and other crops such as wheat (Li et al., 2013; Kaya and Akcura, 2014), maize (Chiremba et al., 2011; Vázquez-Carrillo et al., 2016), and sorghum (Chiremba et al., 2011). Liu et al., (2019) and McNeece et al. (2021) both reported small but significant GxE effects in soybean and other crops such as wheat (Li et al., 2013; Khazratkulova et al., 2015). Since individual varieties differ in their seed composition and since different environments influence seed composition, it is reasonable to anticipate that this is the reason GxE is significant. In addition, correlations were not significant at individual locations on several traits but as a whole they were. This could indicate that the sampling test size was not large enough in each location but collectively necessary to display the correlation.

Conclusion

While it has been conjectured among growers and voiced to breeders that TW is declining, this study demonstrates that new breeding lines are not consistently making the required TW value of 75.7 kg hL^{-1} in the Southeast. However, there is no information available on if it ever met that mark. The MGs and the individual locations met the threshold for Grade 1 soybean (70.8 kg hL^{-1}). The varieties in this study have shown variability in TW. This would be useful when trying to breed for TW. In addition, TW standards need to be re-evaluated in order to eliminate confusion and reexamine the 60 lb bu^{-1} (75.7 kg hL^{-1}) legal weight. Breeders advance material based on a variety of factors and typically yield is the primary driver. It would be advantageous in determining how each seed composition trait impacts TW in order to breed for yield while maintaining this value. In addition, the inconsistency of seed composition across environments further supports that future work needs to be done to fully understand the contribution of oil, protein, seed size and weight on the final value and how to simultaneously breed for it.

References

Bern, C.J., and T.J. Brumm. 2009. Grain Test Weight Deception. Agric. Environ. Ext. Publ. 38(October). https://lib.dr.iastate.edu/extension_ag_pubs/38.

Bernardo, R. 2012. Introduction. Plant Breeding for Quantitative. 2nd ed. Stemma Press, Woodbury,MN. p. 3–14

Boerner, E.. 1916. Bulletin No. 472:Improved Apparatus for Determining the Test Weight of Grain, with a Standard Method of Making the Test. Wa.

Canadian Grain Commission. 2005. Test Weight Conversion Chart.

Chiremba, C., L.W. Rooney, and J.R.N. Taylor. 2011. Relationships between simple grain quality parameters for the estimation of sorghum and maize hardness in commercial hybrid cultivars. Cereal Chem. 88(6): 570–575. doi: 10.1094/CCHEM-06-11-0078.

Davidson, D. 2018a. Understanding Test Weight | ILSoyAdvisor. Illinois Soybean Assoc. https://www.ilsoyadvisor.com/on-farm/ilsoyadvisor/understanding-test-weight (accessed 11 January 2021).

Davidson, D. 2018b. Test Weight Matters in 2019. Illinois Soybean Assoc. https://www.ilsoyadvisor.com/on-farm/ilsoyadvisor/test-weight-matters-2019 (accessed 29 May 2020).

Ding, J.-Q., J.-L. Ma, C.-R. Zhang, H.-F. Dong, Z.-Y. Xi, et al. 2011. QTL mapping for test weight by using F 2:3 population in maize.

Doehlert, D.C., M.S. McMullen, and J.J. Hammond. 2001. Genotypic and environmental effects on grain yield and quality of oat grown in North Dakota. Crop Sci. 41(4): 1066–1072. doi: 10.2135/cropsci2001.4141066x.

Fehr, W.R. 1991. Principles of Cultivar Development: Theory and Technique. 1st ed. Iowa State

University.

Fiedler, J.D., E. Salsman, Y. Liu, M. Michalak de Jiménez, J.B. Hegstad, et al. 2017. Genome-Wide Association and Prediction of Grain and Semolina Quality Traits in Durum Wheat Breeding Populations. Plant Genome 10(3): 1–12. doi: 10.3835/plantgenome2017.05.0038.

Gillen, A.M. 2021. Uniform Soybean Tests Southern States 2020. Stoneville, Mississippi.

Gillen, A.M., and G.W. Shelton. 2020. Uniform Soybean Tests Southern States 2019. Stoneville, Mississippi.

GIPSA. 2006. Grain Inspection Handbook Book III Inspection Procedures.

Haaland, R.L. 1980. Food and Feed Grain Crops. In: Hoveland, C.S., editor, Crop Quality, Storage, and Utilization. American Society of Agronomy, Crop Science Society of America, Madison, Wisconsin. p. 1–34

Hartwig, E.E., and F.I. Collins. 1962. Evaluation of Density Classification as a Selection Technique on Breeding Soybeans for Protein or Oil 1 . Crop Sci. 2(2): 159–162. doi: 10.2135/cropsci1962.0011183x000200020024x.

Hepperly, P.R. 1978. Quality Losses in Phomopsis-Infected Soybean Seeds. Phytopathology 68(12): 1684. doi: 10.1094/phyto-68-1684.

Huber, S.C., K. Li, R. Nelson, A. Ulanov, C.M. DeMuro, et al. 2016. Canopy position has a profound effect on soybean seed composition. PeerJ 2016(9): 1–27. doi: 10.7717/peerj.2452.

Hurburgh, C.R., T.J. Brumm, J.M. Guinn, and R.A. Hartwig. 1990. Protein and oil patterns in U.S. and world soybean markets. J. Am. Oil Chem. Soc. 67(12): 966–973. doi: 10.1007/BF02541859.

Immanuel, S.C., P. Nagarajan, K. Thiyagarajan, M. Bharathi, and R. Rabindran. 2011. Genetic parameters of variability, correlation and pathcoefficient studies for grain yield and other yield Attributes among rice blast disease resistant genotypes of rice (Oryza sativa L.). African J. Biotechnol. 10(17): 3322–3334. doi: 10.5897/AJB10.2575.

Kaya, Y., and M. Akcura. 2014. Effects of genotype and environment on grain yield and quality traits in bread wheat (T. aestivum L.). Food Sci. Technol. 34(2): 386–393. doi: 10.1590/fst.2014.0041.

Khazratkulova, S., R.C. Sharma, A. Amanov, Z. Ziyadullaev, O. Amanov, et al. 2015. Genotype × environment interaction and stability of grain yield and selected quality traits in winter wheat in Central Asia. Turkish J. Agric. For. 39(6): 920–929. doi: 10.3906/tar-1501-24.

Li, Y.F., Y. Wu, N. Hernandez-Espinosa, and R.J. Peña. 2013. Heat and drought stress on durum wheat: Responses of genotypes, yield, and quality parameters. J. Cereal Sci. 57(3): 398–404. doi: 10.1016/j.jcs.2013.01.005.

Liu, J., J. Huang, H. Guo, L. Lan, H. Wang, et al. 2017. The conserved and unique genetic architecture of kernel size and weight in maize and rice. Plant Physiol. 175(2): 774–785. doi: 10.1104/pp.17.00708.

Liu, L., E. Prenger, J. Zhang, B. Little, M.A.R. Mian, et al. 2019. Impact of genotype, seed composition, agronomic trait, and environment on soybean test weight. J. Crop Improv. 33(6): 711–729. doi: 10.1080/15427528.2019.1659205.

Maestri, D.M., D.O. Labuckas, J.M. Meriles, A.L. Lamarque, J.A. Zygadlo, et al. 1998. Seed composition of soybean cultivars evaluated in different environmental regions. J. Sci. Food Agric. 77(4): 494–498. doi: 10.1002/(SICI)1097-0010(199808)77:4<494::AID-JSFA69>3.0.CO;2-B.

McNeece, B.T., J.H. Gillenwater, Z. Li, and M.A.R. Mian. 2021. Assessment of soybean test weight among genotypes, environments, agronomic and seed compositional traits. Agron. J. (March): 1–11. doi: 10.1002/agj2.20665.

Naeve, S.L., and J. Miller-Garvin. 2019. United States Soybean Quality Annual Report.

Piper, E.L., and K.J. Boote. 1999. Temperature and Cultivar Effects on Soybean Seed Oil and Protein Concentrations. J. Am. Oil Chem. Soc. 76(10): 1233–1241.

Pixley, K. V., and K.J. Frey. 1991. Inheritance of Test Weight and Its Relationship with Grain Yield of Oat. Crop Sci. 31(1): 36–40. doi: 10.2135/cropsci1991.0011183x003100010008x.

Prasanth, P.S. 2007. Purple seed stain of soybean - its incidence , effect on seed quality and integrated management. 60(4): 482–488.

Roy, K.W. 1976. Purple Seed Stain of Soybeans. Phytopathology 66(9): 1045. doi: 10.1094/phyto-66-1045.

SAS Institute. 2015. Base SAS 9.4 Procedures Guide Statistical Procedures. Second. Cary, NC.

Smith, R.W. 1940. Circular of National Bureau of Standards C425 Legal Weights per Bushel for Various Commodities. Washington, D C.

Sun, X.-Y., A.E. Ke, W. Ae, Y. Zhao, F.-M. Kong, et al. 2008. QTL analysis of kernel shape and weight using recombinant inbred lines in wheat. Euphytica 165: 615–624. doi: 10.1007/s10681-008-9794-2.

U.S. Soybean Export Council. 2005. U.S. Soy : International Buyers ’ Guide. St.Louis, MO.

United States Department of Agriculture. 1953. Circular No.921:The Test Weight Per Bushel of Grain: Methods of Use and Calibration of the Apparatus. Washington, D C.

Vázquez-Carrillo, M.G., I. Rojas-Martínez, D. Santiago-Ramos, J.L. Arellano-Vázquez, A. Espinosa-Calderón, et al. 2016. Stability Analysis of Yield and Grain Quality Traits for the Nixtamalization Process of Maize Genotypes Cultivated in the Central High Valleys of Mexico. J. Crop Sci. 56(6): 3090–3099. doi: 10.2135/cropsci2015.09.0558.

Wood, C.W., L.J. Krutz, L. Falconer, H.C. Pringle, T. Irby, et al. 2016. Soybean Grade Requirements and Discount Schedules.

Appendix 1.

Table 1. Test Weight prediction equations by machine

Instrument	Regression Equation	R-Square
Perten	Perten= -0.7238+ 1.00065(GAC)	0.904
Volumetric	Vol= 0.8266(Perten)+ 9.3644	0.934
GAC	GAC= 0.8366(Vol)+8.5024	0.854

Table 2. Correlations between Test Weight and Moisture for GAC and Perten.

	Moisture	P-Value
GAC	-0.08	0.05
Perten	-0.20	<0.0001

Table 3. 2019-2020 Southern Uniform Summary Table

	2019	
Location	Entries	MG*
Knoxville, TN	32	V
Pittsburg, KS	32	V
Portageville, MO	32	V
Tallassee, AL	32	V
Florence, SC	17	VI
Plains, GA	17	VI
Tallassee, AL	17	VI
Athens, GA(A)	23	VII
Athens, GA(B)	23	VII
Florence, SC	23	VII
Plains, GA	23	VII
Tallassee, AL	23	VII
	2020	
Location	Entries	MG
Belle Mina, AL	33	V
Knoxville, TN	33	V
Manhattan, KS	33	V
Plymouth, NC	33	V
Athens, GA	20	VI
Kinston, NC	20	VI
Tallassee, AL	20	VI
Athens, GA	19	VII
Kinston, NC	19	VII
Plains, GA	19	VII
Plymouth, NC	19	VII
Tallassee, AL	19	VII

*Maturity Group

Table 4. Analysis of variance for test weight in the Southern Uniform Soybean Tests MG V, VI, VII in 2019 and 2020.

	MG[†] V		MG VI		MG VII	
			2019			
Source	df	Mean Squares	df	Mean Squares	df	Mean Squares
Rep	2	0.36	2	1.86	2	0.54
Variety (G)	31	2.97***	16	18.7***	22	5.63***
Location (E)	3	463***	2	354***	4	71.6***
G x E	93	1.41***	32	7.04***	87	1.48***
Error	250	0.63	74	0.66	218	0.41
Total	379	468.4	126	382.8	333	79.7
			2020			
Rep	2	1.5	2	1.16**	2	0.83
Variety(G)	31	5.58***	19	11.9***	19	29.6***
Location (E)	3	143***	2	47.2***	4	41.8***
G x E	93	3.56	38	0.78***	72	0.80***
Error	264	2.79	97	0.18	185	0.41
Total	393	156.4	158	61.2	282	73.4

*,**,*** indicates significance at P= 0.05, 0.01, 0.0001, respectively.

Table 5. 2019-2020 Southern Uniform Trial Test Weight (kg hL^{-1}) Means Across All Locations for each MG.

MG*	Test Weight	
	2019	
V	71.9	B
VI	71.8	B
VII	73.3	A
LSD	0.379	
P-Value	>0.001	
	2020	
V	72.8	AB
VI	73.2	A
VII	72.4	B
LSD	0.376	
P-Value	>0.001	

Within Maturity Groups, means followed by the same letter do not differ at p=0.05.

Table 6. 2019-2020 Southern Uniform Trial Test Weight (TW) Means for All Locations for MG by Year

Location	MG	TW	
	2019		
Portageville, MO	V	74.2	A
Pittsburg, KS	V	73.1	C
Knoxville, TN	V	71.2	D
Tallassee, AL	V	69.2	E
Florence, SC	VI	74.6	A
Tallassee, AL	VI	71.3	D
Plains, GA	VI	69.2	E
Florence, SC	VII	74.2	A
Athens, GA	VII	73.6	B
Tallassee, AL	VII	73.6	B
Plains, GA	VII	71.4	D
LSD		0.45	
	2020		
Manhattan, KS	V	74.5	A
Plymouth, NC	V	72.6	CD
Belle Mina, AL	V	72.1	CD
Knoxville, TN	V	71.9	CDE
Tallassee, AL	VI	74.5	A
Kinston, NC	VI	73.3	B
Athens, GA	VI	72.3	CD
Tallassee, AL	VII	74.3	A
Plymouth, NC	VII	73.4	B
Plains, GA	VII	72.8	C
Kinston, NC	VII	72.3	CD
Athens, GA	VII	72.1	CD
LSD		0.43	

Means followed by the same letter grouping are not significantly different at P= 0.05

Table 7. Comparisons of Southern Uniform Soybean Trial Test Weight (kg hL^{-1}) Location Means for the MG* V, VI, and VII in 2019 and 2020.

	Location	Means kg hL^{-1}	Range	Std Dev	CV %
		2019			
MG V	Portageville, MO	74.2	72.73-76.81	0.79	1.1
	Pittsburg, KS	73.1	71.34-75.28	0.73	1
	Knoxville, TN	71.2	68.46-75.98	1.12	1.6
	Tallassee, AL	69.2	61.20-71.10	1.28	1.8
MG VI	Florence, SC	74.6	65.65-77.48	2.62	3.5
	Tallassee, AL	71.3	66.63-74.53	1.71	2.4
	Plains, GA	69.2	64.04-72.59	2.17	3.1
MG VII	Florence, SC	74.2	71.28-76.80	1.06	1.4
	Athens, GA(A)	73.6	70.98-75.66	0.92	1.3
	Athens, GA(B)	73.6	72.00-75.66	0.9	1.2
	Tallassee, AL	73.6	70.17-76.03	1.3	1.8
	Plains, GA	71.4	69.35-74.12	1.09	1.5
	LSD	0.45			
		2020			
MG V	Manhattan, KS	74.5	72.27-76.40	0.95	1.3
	Plymouth, NC	72.6	70.35-74.68	0.95	1.3
	Belle Mina, AL	72.1	62.21-78.14	2.38	3.3
	Knoxville, TN	71.9	69.04-73.85	0.77	1.1
MG VI	Tallassee, AL	74.5	71.93-78.37	1.57	2.1
	Kinston, NC	73.3	70.63-75.53	1.27	1.7
	Athens, GA	72.3	69.50-74.64	1.3	1.8
MG VII	Tallassee, AL	74.3	70.32-79.66	1.72	2.32
	Plymouth, NC	73.4	71.51-75.21	0.89	1.21
	Plains, GA	72.8	71.00-75.15	1.15	1.58
	Kinston, NC	72.3	70.71-73.33	0.7	0.97
	Athens, GA	72.1	70.51-74.58	1.07	1.48
	LSD	0.43			

Table 8. 2019 Southern Uniform Trial MG V Test Weight Means for Individual Varieties

Variety	Knoxville, TN	Pittsburg, KS	Portageville, MO	Tallassee, AL
	------------------------kg hL^{-1}	----------------------		
AG 53X6	70.4	72.4	73.8	70.0
AG 55X7	70.2	72.4	73.9	69.1
DA1134-015F	70.6	73.4	74.3	68.7
DA1239-09-L	72.6	73.3	74.6	69.0
Ellis	70.9	73.1	73.7	69.5
JTN-5203	71.7	72.7	75.3	70.1
K15-1809	72.7	73.3	73.9	69.3
N13-273	72.3	73.5	75.2	70.6
N16-590	71.3	72.6	74.4	69.2
N16-600	71.7	73.5	76.1	70.2
N16-8531	72.1	74.6	75.4	69.8
N16-8564	71.7	72.9	74.2	69.7
R13-13997	70.6	72.6	75.3	68.5
R14-1422	70.8	73.3	74.4	69.1
R14-898	70.4	72.5	73.2	68.9
R15-1194	72.6	72.9	74.2	67.5
R15-5695	69.9	71.6	73.2	69.3
S15-15809C	69.0	73.0	74.5	67.1
S15-17812C	69.9	73.7	73.8	67.5
S16-11651C	70.8	72.9	74.2	70.7
S16-15170C	71.1	73.2	73.7	69.6
S16-3739RY	71.2	74.1	74.8	68.6
S16-3747R	70.8	74.1	73.8	68.9
TN11-5140	70.9	73.0	74.0	70.5
TN16-5027	71.9	73.3	73.9	70.2
TN16-510R1	72.1	73.3	74.1	69.5
UA 5612	71.2	73.4	74.8	69.5
V14-0079	70.7	72.8	73.3	67.8
V14-0153	71.3	72.2	73.1	68.7
V14-2421	70.1	73.0	73.4	69.1
V14-3821	72.1	73.1	73.5	69.0
V14-3983	71.7	73.8	74.7	69.1
P-Value	<.0001	<.0001	<.0001	<.0001
Standard Error	0.48	0.3	0.24	0.34

Table . 2019 Southern Uniform Trial MG VI Test Weight Means for Individual Varieties

Variety	Florence, SC	Plains, GA	Tallassee, AL
	-------------kg hL^{-1} ---------------		
AG64X8 RR2X	75.4	70.0	72.0
CZ6316LL	75.8	71.2	74.6
G13-2842R2	77.2	71.4	73.5
G14-6063	72.8	68.2	71.0
G15-1038R2	76.0	69.0	72.2
G15-1811R2	76.6	71.3	68.4
G15-3361R2	76.7	71.9	73.8
G15-3606R2	75.2	70.8	71.1
G15PR-340	71.9	64.9	73.1
N08-105	74.4	66.3	69.4
N09-209	76.0	69.9	70.8
N10-7412	76.0	68.8	68.0
N11-9228	66.0	67.4	71.5
N11-9298	74.5	68.2	71.6
N16-9211	76.4	72.0	71.7
NC-Dilday	73.7	68.3	70.7
NC-Dunphy	73.9	66.0	70.5
P-Value	<.0001	<.0001	<.0001
Standard Error	0.33	0.5	0.79

Table 10. 2019 Southern Uniform Trial MG VII Test Weight Means for Individual Varieties

Variety	Athens, GA(A)	Athens, GA(B)	Florence, SC	Plains, GA	Tallassee, AL
			-------------------------kg hL^{-1} ----------------------		
AG74X8RR2X	73.4	73.3	73.5	71.1	72.5
AGS_738RR	73.5	74.1	74.7	71.6	73
AGS747LL	73.2	73.4	73.1	70.6	72.2
G14_2622R2	72.4	73.4	74.4	70.3	70.3
G14_4364R2	73.7	73.8	74.1	71.2	72.9
G15_2017R2	73.7	74.1	73.9	71.1	73.3
G15_2330R2	73.5	74.1	73.8	71	74.1
G15_2379R2	72.7	72.8	73.9	70.2	74.1
G15PRLL_989	72.5	73.2	73.8	71	73.2
N02_7834	72.4	73.6	74.3	70.9	72.9
N10_764	74.3	75.3	74.2	71.7	73.4
N10_792	71.6	72.2	72.6	71.4	73.5
N11_12528	73.9	74	74.4	70.4	74.8
N11_8098	73.9	74.5	73.5	72.9	71.9
N16_10425	73.7	75	75.7	72.8	75.2
N16_10554	74.9	74.8	73.8	72.2	74.8
N16_9134	74.5	74.3	75.6	71.3	75.3
N16_9198	72.6	72.4	73.9	71.8	73.4
N7003CN	74.3	74.6	74.1	73.3	74
N94_7441	72.7	74.3	75.2	69.9	75.7
NC_Wilder	72.6	73.7	73.7	73.3	73.5
SC17_5517RR1	74.8	75.1	74.5	71.1	74.8
SC17_5537RR2	73.1	73.1	75.3	71.1	73.4
P-Value	<.0001	<.0001	<.0001	<.0001	<.0001
Standard Error	0.26	0.29	0.52	0.37	0.3

Table 11. 2020 Southern Uniform Trial MG V Test Weight Means for Individual Varieties

Variety	Belle Mina, AL	Knoxville, TN	Manhattan, KS	Plymouth, NC
		-------------------------kg hL^{-1} ----------------------		
AG 53X9	72.1	71.6	74.5	70.9
AG 55X7	70.1	71.5	74.4	71.9
AG 56X8	71.7	71.4	74.5	71.6
DA1134-015F	70.6	71.6	74.7	71.8
DA13099-008F	73	70.8	73.2	73.2
Ellis	71	71.7	74.1	71.5
K15-1809	71.4	70.7	74.4	71.7
N16-590	71	72.3	74.5	72.5
N16-8531	71.4	72.7	74.2	73.8
N16-8564	69.2	73	74.4	72
N17-2520	73.1	72.2	74.4	72.1
N17-882	74.1	72	74.1	71.5
NDPJE-14-194	72.4	72.1	74.4	73.4
NDPJE-14-217	69.7	71.6	74.7	73.4
Osage	74.2	72.5	74.9	72
R13-13997	72	72.1	74.5	72.2
R13-14635RR	73.6	71.5	75.4	71.7
R14-1422	75.2	72.2	74.4	73.2
R15-1587	73.1	72.4	75	73.7
S16-14801C	72.9	70.8	74.8	73
S16-14869C	73.1	72.4	74.3	73.8
S16-3739RY	71.2	72.3	74.5	72.8
S16-7840C	71.8	72.4	74.3	73.9
S16-9030C	70.2	71.4	73.8	71.9
S16-9090C	72.2	71.6	75.2	72.3
TN09-008	72.3	71.7	73.9	73.7
TN11-5140	72.2	71.5	74	72.1
TN16-5024	71.4	72.7	75	73.2
V14-0079	71.7	71.2	74.8	71.8
V15-1815DI	72.2	72.1	74.7	73.6
V15-1872	73.6	72.1	73.9	74.3
V15-2261ST	72.4	71.6	74.4	72.3
V16-0709PR	72.6	71.5	75.2	71.5
P-Value	<.0001	<.0001	<.0001	<.0001
Standard Error	0.95	0.36	0.58	0.24

Table 12. 2020 Southern Uniform Trial MG VI Test Weight Means for Individual Varieties

Variety	Athens, GA	Kinston, NC	Tallassee, AL
	------------------------kg hL-1 ---------------------		
AG64X8 RR2X	71.6	72.2	72.8
CZ6316LL	73.8	74.3	74.6
G15-1038R2	72.3	73.5	75.7
G15-1811R2	73	74.4	76.1
G15-3361R2	71.6	72.5	74
G16-4162R2	70.8	71.9	73.4
G16-4995R2	71.7	73.1	73.6
G16-8779	74.4	75.3	77.6
G16LL-10015	71.1	71.8	73.5
N10-7412	72.2	73.6	75.9
N11-12528	73.4	75.1	75.3
N16-10756	73.3	75.4	77.9
N16-559	70.2	72	72.8
N16-8876	73.1	73.8	74.2
N16-9064	73.6	74.7	74.9
N16-9211	72.5	72.6	74.7
N16-D49-2524	73.4	73.2	73.6
N17-2535	71.5	72.1	73.4
NC-Dilday	71.8	72.9	73.4
NC-Dunphy	69.7	70.8	72.3
P-Value	<.0001	<.0001	<.0001
Standard Error	0.32	0.14	0.37

Table 13. 2020 Southern Uniform Trial MG VII Test Weight Means for Individual Varieties

Variety	Athens, GA	Kinston, NC	Plains, GA	Plymouth, NC	Tallassee, AL
			-------------------------kg hL-1 ----------------------		
AG74X8 RR2X	72.5	72.6	72.8	73.1	75.4
AGS 747LL	70.8	71.1	71.2	71.9	73.5
AGS-738RR	72.7	73	73.6	74.2	78.3
G15-2017R2	71.1	72.1	72.1	72.6	73
G15-2379R2	71.1	72.2	71.6	73.2	73.8
G16-4418R2	70.8	70.9	71.2	72	72.1
G16-5129R2	72	72.3	72.3	73.4	74
G16-5923R2	71.8	72.3	72.3	73.4	73.5
G16-5967R2	71	72	71.8	72.6	73.4
G16LL-10193	71.2	71.4	72	72.7	73
N16-10518	73.4	72.3	74.1	74.5	75.4
N16-10740	73.5	73	74.2	74.8	75.6
N16-9124	72	71.4	72.2	72.8	73.5
N16-9134	73.1	73.1	74.3	74.4	75.2
N16-9198	71.9	71.9	72.2	73	73.7
N7003CN	72.3	72.9	74.1	73.4	74.5
N94-7441	74.5	72.8	75	74.5	76.7
NC-Wilder	72.7	72.9	73.3	74.1	73.2
SC17-5537RR2	71.6	72.4	72.7	72.9	74.5
P-Value	<.0001	<.0001	<.0001	<.0001	<.0001
Standard Error	0.24	0.15	0.2	0.19	0.73

Table.14 Broad sense heritability estimates for Test Weight in 2019 and 2020.

2019	
MG* V	0.56
MG VI	0.88
MG VII	0.65
2020	
MG V	0.36
MG VI	0.93
MG VII	0.65

Significant at P=0.05

Table 15. Correlation of Test Weight with agronomic traits and seed composition for 2019.

	Yield	Height	Seed Size	Protein	Oil
MG† V					
Knoxville, TN	-0.11	-0.26	-0.41*	0.23	-0.55**
Pittsburg, KS	0.24	0.1	-0.31	-0.01	-0.23
Portageville, MO	-0.32	0.08	-0.50**	0.3	-0.52**
Tallassee, AL	0.047	-0.02	-0.45**	0.08	-0.53**
MGV Total	0.18*	-0.47***	-0.77***	-0.23**	-0.55***
MG VI					
Florence, SC	-0.02	0.2	.	0.06	-0.31
Plains, GA	-0.3	-0.1	-0.50*	0.34	-0.58**
Tallassee, AL	0.21	0.46	-0.25	0.31	-0.27
MGVI Total	-0.63***	-0.35**	-0.18	0.33**	-0.51***
MG VII					
Athens, GA(A)	-0.51*	-0.31	-0.16	0.09	-0.99***
Athens, GA(B)	-0.23	-0.14	-0.26	0.16	-0.07
Florence, SC	-0.39	0.14	.	0.32	-0.50*
Plains, GA	0.2	-0.001	0.08	-0.06	0.14
Tallassee, AL	0.26	-0.02	-0.67**	0.42*	-0.52**
MGVII Total	-0.39***	0.02	-0.12	0.34**	-0.94***
Across all tests	-0.17**	-0.17**	-0.46***	0.03	-0.85***

*,**,*** indicates significance at P= 0.05, 0.01, 0.0001, respectively.

Table 16. Correlation of test weight with agronomic traits and seed composition for 2020.

	Yield	Height	Seed Size	Protein	Oil
MG[†] V					
Belle Mina, AL	-0.19	-0.02	0.24	-0.04	0.13
Knoxville, TN	-0.28	0.009	.	0.13	-0.15
Manhattan, KS	-0.005	0.09	-0.06	0.009	-0.09
Plymouth, NC	0.28	0.03	-0.01	-0.2	-0.04
MG V Total	0.0008	0.58***	-0.37**	-0.52***	-0.48***
MG VI					
Athens, GA	-0.01	0.1	-0.41	-0.05	-0.18
Kinston, NC	-0.3	0.31	-0.3	0.13	-0.37
Tallassee, AL	-0.01	0.28	-0.45*	0.04	-0.22
MG VI Total	-0.41**	-0.17	-0.26*	0.08	-0.21
MG VII					
Athens, GA	-0.07	-0.29	-0.63**	0.42	-0.32
Kinston, NC	-0.001	0.02	-0.17	-0.14	0.1
Plains, GA	-0.25	-0.29	-0.52*	0.3	-0.41
Plymouth, NC	-0.46*	-0.26	-0.49*	0.21	0.004
Tallassee, AL	-0.18	-0.33	-0.33	0.11	-0.3
MG VII Total	-0.06	-0.24**	-0.39***	0.29**	-0.18
Across all groups	-0.07	0.25***	-0.33***	-0.08509	-0.3***

*,**,*** indicates significance at P= 0.05, 0.01, 0.0001, respectively.

Table 17. 2019 Southern Uniform Test Seed Yield Means for Individual Varieties for MG V

Variety	Knoxville, TN	Pittsburg, KS	Portageville, MO(A)	Tallassee, AL
	--------------------------Bushels per Acre--------------------------			
Ellis	90.1	50.8	55.0	32.9
AG 53X6	65.8	42.2	49.0	40.5
JTN-5203	63.7	56.1	45.2	32.4
UA 5612	80.2	46.1	52.8	31.2
TN11-5140	78.9	46.0	49.5	40.2
AG 55X7	59.6	50.4	54.8	37.2
DA1134-015F	87.6	51.0	54.5	30.8
DA1239-09-L	74.0	49.2	54.1	35.8
K15-1809	87.9	54.8	54.9	39.1
N13-273	63.0	41.2	37.6	33.8
N16-590	79.3	48.3	50.9	40.3
N16-600	64.8	45.1	44.5	41.2
N16-8531	63.2	45.7	59.4	24.1
N16-8564	59.2	49.3	52.0	39.0
R13-13997	70.9	47.0	51.0	38.6
R14-898	83.1	45.4	51.5	41.6
R14-1422	77.4	38.0	44.9	38.1
R15-1194	69.9	45.4	45.1	36.9
R15-5695	73.1	41.3	49.0	41.8
S15-15809C	72.2	39.5	52.0	31.7
S15-17812C	74.0	51.6	58.0	40.6
S16-11651C	70.8	50.8	52.1	36.8
S16-15170C	78.3	49.0	53.7	35.4
S16-3739RY	84.1	55.3	56.8	33.1
S16-3747R	79.7	49.2	57.1	36.9
TN16-510R1	72.0	54.1	51.6	25.8
TN16-5027	80.0	47.4	53.9	33.2
V14-0079	67.6	49.9	52.5	31.7
V14-0153	60.4	44.7	49.1	31.4
V14-2421	74	42.3	56.7	33.1
V14-3821	67.8	43.6	52.6	32.6
Mean	73.1	47.5	51.4	35.1
LSD (0.05)	18.5	3.70	4.60	11.2

Table 18. 2019 Southern Uniform Test Seed Yield Means for Individual Varieties for MG VI

Variety	Florence, SC	Plains, GA	Tallassee, AL
	-------------------------Bushels per Acre-------------------------		
AG64X8 RR2X	27.9	59.9	44.7
NC-Dunphy	25.5	59.4	39.7
NC-Dilday	29.4	57.0	47.5
CZ6316LL	28.3	55.3	40.8
G13-2842R2	37.1	63.9	44.3
G14-6063	37.7	57.5	45.8
G15-1038R2	39.2	60.4	40.6
G15-1811R2	37.1	59.1	44.0
G15-3361R2	36.4	60.9	52.5
G15-3606R2	34.8	53.8	41.2
G15PR-340	30.6	60.3	33.1
N08-105	27.4	68.3	34.0
N09-209	25.4	57.9	39.9
N10-7412	29.5	54.5	37.9
N11-9228	36.9	51.6	32.0
N11-9298	39.5	54.9	39.1
N16-9211	39.5	43.8	50.6
Mean	33.1	57.6	41.6
LSD (0.05)	4.70	6.00	18.8

Table 19. 2019 Southern Uniform Test Seed Yield Means for Individual Varieties for MG VII

Variety	Athens, GA(A)	Athens, GA(B)	Florence, SC	Plains, GA	Tallassee, AL
	--------------------------Bushels per Acre--------------------------				
AGS-738RR	.	.	.	.	.
AG74X8 RR2X	53.8	51.1	40.4	54.4	35.2
N7003CN	43.8	41.5	45.3	59.7	30.5
NC-Wilder	50.9	51.2	41.5	58.1	31.1
AGS 747LL	50.5	51.3	51.4	53.7	26.5
G14-2622R2	52.2	51.4	47.3	48.5	21.3
G14-4364R2	55.6	50.6	42.8	57.0	37.6
G15-2017R2	53.3	45.5	46.4	61.3	31.0
G15-2330R2	48.2	50.6	46.8	58.6	32.8
G15-2379R2	44.8	47.5	47.0	50.9	30.2
G15PRLL-989	49.7	54.3	38.6	55.0	32.1
N02-7834	41.7	46.8	30.7	53.8	35.1
N10-764	42.0	48.7	35.5	56.6	27.5
N10-792	52.1	50.5	36.9	58.7	44.0
N11-8098	39.9	47.0	35.6	47.5	24.8
N11-12528	49.0	47.8	38.0	56.5	32.5
N16-9134	43.6	41.2	41.0	43.3	33.1
N16-9198	51.3	43.9	33.8	47.1	33.5
N16-10425	50.9	47.1	31.3	52.3	24.9
N16-10554	45.2	47.0	36.5	49.6	34.0
N94-7441	50.9	46.5	22.3	40.8	32.4
SC17-5517RR1	41.0	49.1	40.6	50.8	27.6
SC17-5537RR2	43.7	44.1	38.4	53.6	31.9
Mean	47.9	47.9	39.5	53.1	31.3
LSD (0.05)	7.20	7.80	3.50	7.00	10.8

Table 20. 2020 Southern Uniform Test Seed Yield for Individual Varieties for MG V

Variety	Belle Mina, AL	Knoxville, TN	Manhattan, KS	Plymouth, NC
	-------------------------Bushels per Acre---------------------			
AG 53X9	29.9	83.4	70.8	28.3
AG 55X7	34.4	67.9	56.9	36.5
AG 56X8	30.8	71.8	57.0	36.0
DA1134-015F	28.1	76.7	57.9	27.4
DA13099-008F	33.9	65.4	60.8	28.2
Ellis	32.1	52.0	58.4	29.7
K15-1809	37.8	77.1	53.7	30.8
N16-590	31.8	69.5	47.5	31.2
N16-8531	26.9	71.7	51.7	35.7
N16-8564	23.6	69.3	48.6	35.1
N17-2520	24.8	72.8	49.6	33.4
N17-882	24.5	57.2	49.4	25.0
NDPJE-14-194	21.8	74.5	51.6	32.4
NDPJE-14-217	17.9	85.9	55.2	35.8
Osage	25.6	63.2	51.9	37.2
R13-13997	32.3	70.1	48.3	32.9
R13-14635RR	31.4	76.4	51.2	36.4
R14-1422	20.0	73.9	49.0	38.7
R15-1587	28.9	58.6	55.8	36.7
S16-14801C	38.6	88.5	63.9	29.7
S16-14869C	33.6	88.0	54.9	32.5
S16-3739RY	31.5	74.9	58.8	26.2
S16-7840C	33.0	74.8	57.7	32.4
S16-9030C	31.3	86.9	50.1	33.1
S16-9090C	33.2	81.0	53.7	30.9
TN09-008	27.0	72.1	52.1	30.4
TN11-5140	28.6	70.0	43.5	41.0
TN16-5024	30.3	62.8	55.1	28.8
V14-0079	14.9	70.0	49.3	31.1
V15-1815DI	30.2	69.9	49.1	35.7
V15-1872	31.6	75.7	47.0	42.3
V15-2261ST	27.3	85.6	50.5	34.7
V16-0709PR	28.2	72.2	47.1	29.2
Mean	29.0	73.0	53.3	32.9
LSD (0.05)	9.60	11.8	5.50	7.30

Table 21. 2020 Southern Uniform Test Seed Yield for Individual Varieties for MG VI

Variety	Athens, GA	Kinston, NC	Tallassee, AL
	-------------------------Bushels per Acre-------------------------		
AG64X8 RR2X	62.4	44.2	43.2
CZ6316LL	64.9	39.2	42.8
G15-1038R2	63.4	42.8	42.4
G15-1811R2	67.9	42.0	50.9
G15-3361R2	69.4	44.8	41.3
G16-4162R2	60.6	46.8	37.8
G16-4995R2	62.0	41.9	44.6
G16-8779	63.8	43.6	54.8
G16LL-10015	57.7	41.1	43.6
N10-7412	62.3	40.0	41.2
N11-12528	62.4	34.4	37.7
N16-10756	63.2	34.4	38.2
N16-559	58.0	36.4	49.6
N16-8876	69.9	45.8	46.3
N16-9064	60.8	43.7	53.4
N16-9211	63.4	42.1	47.1
N16-D49-2524	56.0	36.7	30.9
N17-2535	64.3	42.5	45.6
NC-Dilday	75.8	38.3	50.2
NC-Dunphy	68.6	41.6	54.2
Mean	63.8	41.1	44.8
LSD (0.05)	7.20	4.40	16.5

Table 22. 2020 Southern Uniform Test Seed Yield Means for Individual Varieties for MG VII

Variety	Athens, GA	Kinston, NC	Plains, GA	Plymouth, NC	Tallassee, AL
	--------------------------Bushels per Acre--------------------------				
AG74X8 RR2X	65.0	35.2	52.3	32.6	58.4
AGS 747LL	47.0	37.3	75.2	34.1	51.5
AGS-738RR	63.9	37.5	76.1	35.8	56.0
G15-2017R2	62.8	37.0	82.2	37.1	48.3
G15-2379R2	65.9	37.3	80.6	37.9	57.5
G16-4418R2	65.7	31.2	86.5	41.1	56.2
G16-5129R2	55.8	34.5	78.7	34.1	49.3
G16-5923R2	64.0	36.6	81.2	35.6	55.9
G16-5967R2	66.0	32.9	85.7	38.9	56.4
G16LL-10193	56.9	32.0	78.9	35.6	49.5
N16-10518	64.2	33.7	75.8	31.8	49.1
N16-10740	49.3	26.5	69.8	32.2	36.9
N16-9124	58.0	25.8	67.1	28.6	57.6
N16-9134	55.5	32.4	73.6	30.4	52.4
N16-9198	61.3	30.5	75.5	38.9	63.5
N7003CN	38.8	35.0	73.1	33.3	48.5
N94-7441	64.5	26.7	79.1	34.0	51.3
NC-Wilder	56.1	30.6	85.5	36.4	56.1
SC17-5537RR2	60.5	33.5	75.2	36.8	55.5
Mean	59.0	33.0	76.4	35.0	53.2
LSD (0.05)	11.7	7.50	8.00	7.30	12.9

Table 23. 2019 Southern Uniform Test Plant Height Means for Individual Varieties for MG V

Variety	Knoxville, TN	Pittsburg, KS	Portageville, MO	Tallassee, AL
	---Inches---			
Ellis	24.0	31.0	22.0	36.0
AG 53X6	25.0	30.0	30.0	37.0
JTN-5203	25.0	31.0	22.0	32.0
UA 5612	33.0	39.0	28.0	43.0
TN11-5140	34.0	36.0	29.0	41.0
AG 55X7	23.0	29.0	24.0	32.0
DA1134-015F	30.0	34.0	24.0	43.0
DA1239-09-L	30.0	32.0	28.0	40.0
K15-1809	25.0	27.0	22.0	34.0
N13-273	24.0	32.0	30.0	36.0
N16-590	29.0	31.0	25.0	36.0
N16-600	25.0	33.0	27.0	32.0
N16-8531	22.0	32.0	25.0	27.0
N16-8564	22.0	33.0	26.0	37.0
R13-13997	31.0	35.0	26.0	40.0
R14-898	33.0	36.0	29.0	41.0
R14-1422	31.0	33.0	27.0	32.0
R15-1194	29.0	34.0	23.0	32.0
R15-5695	27.0	31.0	25.0	36.0
S15-15809C	32.0	38.0	32.0	45.0
S15-17812C	24.0	30.0	25.0	29.0
S16-11651C	29.0	34.0	29.0	40.0
S16-15170C	36.0	31.0	37.0	37.0
S16-3739RY	35.0	32.0	30.0	42.0
S16-3747R	34.0	34.0	27.0	28.0
TN16-510R1	23.0	34.0	28.0	39.0
TN16-5027	27.0	33.0	27.0	40.0
V14-0079	21.0	29.0	19.0	38.0
V14-0153	26.0	30.0	25.0	38.0
V14-2421	28.0	33.0	29.0	36.0
V14-3821	23.0	33.0	24.0	29.0
V14-3983	24.0	31.0	26.0	35.0
Mean	28.0	33.0	26.0	36.0
LSD (0.05)	4.00	5.00	3.00	11.0

Table 24. 2019 Southern Uniform Test Plant Height Means for Individual Varieties for MG VI

Variety	Florence, SC	Plains, GA	Tallassee, AL
	--------------------------Inches--------------------------		
AG64X8 RR2X	20.0	29.0	36.0
NC-Dunphy	12.0	21.0	32.0
NC-Dilday	16.0	25.0	33.0
Z6316LL	20.0	27.0	38.0
G13-2842R2	20.0	27.0	40.0
G14-6063	18.0	29.0	35.0
G15-1038R2	20.0	33.0	40.0
G15-1811R2	22.0	32.0	41.0
G15-3361R2	20.0	29.0	40.0
G15-3606R2	15.0	25.0	28.0
G15PR-340	23.0	32.0	35.0
N08-105	17.0	29.0	28.0
N09-209	16.0	26.0	31.0
N10-7412	20.0	31.0	31.0
N11-9228	17.0	26.0	34.0
N11-9298	23.0	31.0	38.0
N16-9211	20.0	21.0	31.0
Mean	19.0	28.0	35.0
LSD (0.05)	3.00	5.00	6.00

Table 25. 2019 Southern Uniform Test Plant Height Means for Individual Varieties for MG VII

Variety	Athens, GA(A)	Athens, GA(B)	Florence, SC	Plains, GA	Tallassee, AL
			------------------------------Inches------------------------------		
AGS-738RR	.	.	.	.	.
AG74X8 RR2X	40.0	40.0	18.0	28.0	32.0
N7003CN	38.0	38.0	21.0	33.0	35.0
NC-Wilder	41.0	40.0	22.0	29.0	33.0
AGS 747LL	42.0	48.0	23.0	31.0	36.0
G14-2622R2	45.0	42.0	24.0	34.0	27.0
G14-4364R2	43.0	41.0	19.0	31.0	38.0
G15-2017R2	41.0	39.0	24.0	30.0	35.0
G15-2330R2	40.0	39.0	19.0	30.0	35.0
G15-2379R2	43.0	43.0	24.0	32.0	35.0
G15PRLL-989	41.0	41.0	20.0	32.0	35.0
N02-7834	38.0	37.0	21.0	30.0	32.0
N10-764	38.0	40.0	16.0	28.0	30.0
N10-792	41.0	40.0	19.0	31.0	34.0
N11-8098	38.0	38.0	18.0	31.0	31.0
N11-12528	42.0	44.0	19.0	30.0	34.0
N16-9134	35.0	35.0	21.0	25.0	30.0
N16-9198	40.0	37.0	18.0	22.0	36.0
N16-10425	39.0	42.0	24.0	30.0	30.0
N16-10554	39.0	39.0	23.0	26.0	31.0
N94-7441	41.0	40.0	19.0	24.0	28.0
SC17-5517RR1	41.0	40.0	25.0	29.0	34.0
SC17-5537RR2	43.0	46.0	20.0	32.0	35.0
Mean	40.0	41.0	21.0	29.0	33.0
LSD (0.05)	3.00	4.00	3.00	3.00	5.00

Table 26. 2020 Southern Uniform Test Plant Height Means for Individual Varieties for MG V

Variety	Belle Mina, AL	Knoxville, TN	Manhattan, KS	Plymouth, NC
	-------------------------------	Inches	-------------------------------	
AG 53X9	35.7	26.0	43.0	21.0
AG 55X7	32.3	20.7	42.3	21.5
AG 56X8	35.3	23.7	46.7	28.0
DA1134-015F	35.7	23.7	39.0	24.5
DA13099-008F	32.3	21.7	38.3	24.0
Ellis	32.7	17.7	40.7	22.5
K15-1809	28.3	19.3	36.7	19.0
N16-590	35.7	24.3	39.7	25.5
N16-8531	29.0	22.7	41.7	22.0
N16-8564	33.7	22.0	41.7	24.0
N17-2520	35.7	25.0	45.7	25.5
N17-882	35.0	22.3	44.0	23.0
NDPJE-14-194	36.7	25.3	44.7	25.5
NDPJE-14-217	33.3	24.3	40.7	25.0
Osage	30.7	25.7	38.3	23.5
R13-13997	36.7	24.0	43.3	24.0
R13-14635RR	32.0	34.3	44.3	34.0
R14-1422	34.7	24.7	43.0	24.0
R15-1587	29.7	18.3	40.0	22.5
S16-14801C	33.7	25.3	41.7	25.5
S16-14869C	38.0	27.7	44.7	27.0
S16-3739RY	38.7	26.0	47.0	28.0
S16-7840C	40.3	30.3	49.0	29.5
S16-9030C	39.3	26.3	45.0	27.5
S16-9090C	36.7	27.0	45.3	28.0
TN09-008	31.0	19.0	40.7	21.5
TN11-5140	36.0	22.7	43.3	27.5
TN16-5024	29.7	19.7	39.7	21.5
V14-0079	27.0	19.7	39.0	19.5
V15-1815DI	36.3	22.0	41.7	22.5
V15-1872	37.7	24.7	42.7	27.0
V15-2261ST	34.7	28.3	42.3	26.5
V16-0709PR	32.7	32.3	47.3	29.0
Mean	34.0	24.0	43.0	25.0
LSD (0.05)	5.00	4.00	4.00	4.00

Table 27. 2020 Southern Uniform Test Plant Height Means for Individual Varieties for MG VI

Variety	Athens, GA	Kinston, NC	Tallassee, AL
	--------------------------------Inches-------------------------------		
AG64X8 RR2X	41.0	39.0	30.0
CZ6316LL	37.7	37.5	31.0
G15-1038R2	37.0	37.5	32.5
G15-1811R2	40.3	39.5	35.0
G15-3361R2	38.0	40.5	28.5
G16-4162R2	40.3	40.0	30.5
G16-4995R2	43.3	40.5	28.5
G16-8779	34.7	35.5	38.0
G16LL-10015	43.3	44.5	39.0
N10-7412	36.3	38.5	30.5
N11-12528	40.0	41.0	28.5
N16-10756	45.7	39.5	32.5
N16-559	38.7	34.5	30.0
N16-8876	38.0	38.5	35.5
N16-9064	38.3	38.0	34.5
N16-9211	35.0	35.5	29.5
N16-D49-2524	35.7	34.5	29.0
N17-2535	41.3	36.5	34.5
NC-Dilday	35.3	31.5	37.0
NC-Dunphy	28.3	25.5	29.0
Mean	38.0	37.0	32.0
LSD (0.05)	3.00	3.00	12.0

Table 28. 2020 Southern Uniform Test Plant Height Means for Individual Varieties for MG VII

Variety	Athens, GA	Kinston, NC	Plains, GA	Plymouth, NC	Tallassee, AL
	------------------------------	---------------	Inches	---------------	------------------------------
AG74X8 RR2X	41.7	33.5	22.3	24.0	42.0
AGS 747LL	37.3	35.0	33.3	31.0	40.7
AGS-738RR	38.7	35.5	31.7	27.5	36.0
G15-2017R2	43.3	39.0	35.3	30.0	40.7
G15-2379R2	40.7	41.0	32.3	30.0	43.0
G16-4418R2	45.7	37.5	37.7	31.0	40.7
G16-5129R2	46.7	39.0	39.0	33.0	43.7
G16-5923R2	42.3	38.5	33.3	30.5	37.0
G16-5967R2	35.7	40.0	37.3	33.5	38.0
G16LL-10193	48.0	40.0	38.7	32.5	41.0
N16-10518	37.7	30.5	29.7	28.0	34.3
N16-10740	37.3	39.0	32.3	30.5	31.3
N16-9124	33.7	28.0	29.3	27.5	31.7
N16-9134	33.3	34.5	33.0	29.0	34.7
N16-9198	42.0	35.0	36.0	28.0	38.3
N7003CN	40.0	35.5	34.3	27.5	39.3
N94-7441	41.7	31.5	33.7	30.5	35.7
NC-Wilder	42.0	39.0	35.0	29.0	33.0
SC17-5537RR2	46.7	40.5	34.7	32.0	40.0
Means	41.0	36.0	34.0	30.0	38.0
LSD (0.05)	2.00	5.00	3.00	4.00	8.00

Table 29. 2019 Southern Uniform Test Seed Size Means for Individual Varieties for MG V

Variety	Knoxville, TN	Pittsburg, KS	Portageville, MO	Tallassee, AL
	----------------------Grams per 100 Seed------------------------			
Ellis	12.5	12.2	10.4	17.4
AG 53X6	15.0	16.3	13.0	17.0
JTN-5203	12.5	14.6	10.7	16.1
UA 5612	12.8	13.1	10.2	16.0
TN11-5140	14.1	13.4	11.1	16.7
AG 55X7	13.1	13.6	10.9	14.4
DA1134-015F	13.5	12.5	10.8	16.0
DA1239-09-L	13.8	15.6	12.3	16.7
K15-1809	12.5	13.3	11.1	15.3
N13-273	13.2	13.5	9.80	13.6
N16-590	15.7	14.8	12.4	17.7
N16-600	11.8	13.0	10.4	14.7
N16-8531	12.7	12.4	10.2	16.2
N16-8564	11.6	12.1	9.70	16.3
R13-13997	15.3	11.0	11.7	17.8
R14-898	15.0	15.7	13.5	19.3
R14-1422	13.6	12.4	10.2	14.8
R15-1194	14.4	13.7	11.6	16.9
R15-5695	16.6	14.1	12.3	17.0
S15-15809C	16.4	13.9	12.1	18.9
S15-17812C	13.8	11.9	10.8	17.5
S16-11651C	13.9	13.7	10.4	14
S16-15170C	17.0	18.8	13.4	16.8
S16-3739RY	14.1	12.1	10.7	16.9
S16-3747R	16.2	15.1	12.0	16.5
TN16-510R1	10.7	10.4	8.90	16.6
TN16-5027	14.5	13.8	12.1	18.5
V14-0079	12.9	12.7	10.7	17.0
V14-0153	15.7	18.5	14.0	21.1
V14-2421	15.7	15.7	12.7	19.3
V14-3821	16.9	16.3	14.4	18.3
V14-3983	13.7	14.1	12.2	17.6
Mean	14.1	13.9	11.5	16.8
LSD (0.05)	.	.	0.60	2.00

Table 30. 2019 Southern Uniform Test Seed Size for Individual Varieties for MG VI

Variety	Florence, SC	Plains, GA	Tallassee, AL
	-------------Grams per 100 Seed-------------------		
AG64X8 RR2X	.	13.5	14.1
NC-Dunphy	.	15.9	18.0
NC-Dilday	.	17.4	17.4
CZ6316LL	.	12.9	15.2
G13-2842R2	.	15.0	17.5
G14-6063	.	17.2	17.5
G15-1038R2	.	13.6	14.2
G15-1811R2	.	12.8	14.1
G15-3361R2	.	12.1	12.2
G15-3606R2	.	14.4	15.8
G15PR-340	.	12.7	14.2
N08-105	.	16.4	17.1
N09-209	.	16.2	16.5
N10-7412	.	15.2	15.1
N11-9228	.	15.1	14.9
N11-9298	.	16.1	16.9
N16-9211	.	9.40	13.5
Mean	.	14.5	15.5
LSD(0.05)	.	1.30	3.80

Table 31. 2019 Southern Uniform Test Seed Size Means for Individual Varieties for MG VII

Variety	Athens, GA(A)	Athens, GA(B)	Florence, SC	Plains, GA	Tallassee, AL
	-------------------Grams per 100 Seed----------------------				
AGS-738RR	.	.	.	.	.
AG74X8 RR2X	17.6	15.5	.	15.3	16.7
N7003CN	17.4	14.0	.	15.7	19.7
NC-Wilder	17.2	14.0	.	14.9	14.5
AGS 747LL	15.8	13.5	.	14.3	16.8
G14-2622R2	17.6	13.9	.	12.5	15.9
G14-4364R2	18.4	14.5	.	16.1	16.4
G15-2017R2	16.0	13.2	.	14.7	15.6
G15-2330R2	16.1	13.1	.	13.5	15.0
G15-2379R2	15.3	13.5	.	12.1	14.8
G15PRLL-989	17.5	14.1	.	14.7	15.0
N02-7834	17.7	13.8	.	15.6	16.7
N10-764	17.3	13.9	.	14.2	14.5
N10-792	18.0	16.2	.	15.7	16.4
N11-8098	19.2	18.7	.	16.1	22.1
N11-12528	15.2	12.7	.	13.9	14.3
N16-9134	12.4	9.30	.	9.50	11.3
N16-9198	10.3	9.30	.	8.60	10.9
N16-10425	11.5	9.50	.	9.70	10.0
N16-10554	11.4	8.80	.	8.90	10.8
N94-7441	9.20	7.40	.	8.50	9.00
SC17-5517RR1	14.6	12.3	.	13.0	12.7
SC17-5537RR2	17.0	15.1	.	15.1	15.2
Mean	15.6	13.0	.	13.3	14.7
LSD (0.05)	1.10	1.50	.	1.20	2.30

Table 32. 2020 Southern Uniform Test Seed Size Means for Individual Varieties for MG V

Variety	Belle Mina, AL	Knoxville, TN	Manhattan, KS	Plymouth, NC
	--------------------------Grams per 100 Seed-----------------------------			
AG 53X9	19.6	.	15.0	13.7
AG 55X7	17.2	.	11.7	11.4
AG 56X8	20.1	.	13.0	13.5
DA1134-015F	17.5	.	12.3	12.1
DA13099-008F	18.5	.	13.3	12.4
Ellis	15.3	.	9.30	10.4
K15-1809	16.9	.	11.7	11.7
N16-590	20.7	.	13.3	10.8
N16-8531	16.8	.	12.0	11.6
N16-8564	16.4	.	10.3	11.9
N17-2520	21.9	.	15.3	17.3
N17-882	19.8	.	12.3	13.8
NDPJE-14-194	19.4	.	13.0	14.2
NDPJE-14-217	19.2	.	12.7	14.7
Osage	16.8	.	10.7	10.6
R13-13997	20.8	.	12.3	13.4
R13-14635RR	17.2	.	13.0	12.5
R14-1422	16.9	.	11.7	11.3
R15-1587	16.4	.	10.7	10.4
S16-14801C	18.0	.	12.3	12.2
S16-14869C	18.6	.	11.7	13.0
S16-3739RY	18.1	.	10.7	11.3
S16-7840C	17.0	.	12.3	12.9
S16-9030C	16.4	.	11.3	11.4
S16-9090C	17.9	.	12.3	12.2
TN09-008	18.2	.	14.7	14.2
TN11-5140	19.3	.	12.0	12.8
TN16-5024	15.3	.	10.7	11.5
V14-0079	18.0	.	12.0	11.1
V15-1815DI	20.8	.	12.7	13.4
V15-1872	20.4	.	13.7	13.9
V15-2261ST	17.1	.	12.0	12.8
V16-0709PR	23.5	.	14.7	15.5
Mean	18.4	.	12.3	12.6
LSD (0.05)	2.30	.	1.20	1.80

Table 33. 2020 Southern Uniform Test Seed Size Means for Individual Varieties for MG VI

Variety	Athens, GA	Kinston, NC	Tallassee, AL
	------------Grams per 100 Seed-------------		
AG64X8 RR2X	13.7	14.0	14.1
CZ6316LL	13.4	13.3	14.4
G15-1038R2	13.4	14.5	14.7
G15-1811R2	14.2	14.4	14.8
G15-3361R2	13.2	13.4	12.8
G16-4162R2	15.1	14.6	14.0
G16-4995R2	13.3	13.6	13.6
G16-8779	14.6	15.5	14.5
G16LL-10015	14.3	14.3	15.2
N10-7412	14.5	15.0	15.0
N11-12528	13.7	11.6	12.9
N16-10756	14.4	12.2	12.4
N16-559	16.4	15.3	18.5
N16-8876	14.2	15.1	15.3
N16-9064	16.1	15.3	16.9
N16-9211	11.1	10.8	13.2
N16-D49-2524	13.4	13.2	13.7
N17-2535	18.9	18.4	19.3
NC-Dilday	17.8	17.1	19.6
NC-Dunphy	17.5	15.6	18.0
Mean	14.7	14.4	15.1
LSD (0.05)	0.90	0.60	2.50

Table 34. 2020 Southern Uniform Test Seed Size Means for Individual Varieties for MG VII

Variety	Athens, GA	Kinston, NC	Plains, GA	Plymouth, NC	Tallassee, AL
	--------------------------Grams per 100 Seed----------------------------				
AG74X8 RR2X	17.8	15.6	16.7	15.8	15.3
AGS 747LL	16.3	14.5	16.8	15.0	13.6
AGS-738RR	14.6	13.4	15.3	13.6	14.1
G15-2017R2	15.7	14.0	15.9	14.5	14.1
G15-2379R2	14.9	14.6	15.3	14.9	14.4
G16-4418R2	14.3	13.7	14.7	14.1	13.1
G16-5129R2	16.2	15.6	16.9	15.6	14.7
G16-5923R2	15.1	14.5	15.3	14.4	13.9
G16-5967R2	18.0	16.9	17.7	17.7	16.5
G16LL-10193	18.1	16.1	17.7	15.4	16.9
N16-10518	10.7	10.5	11.0	10.5	10.3
N16-10740	10.7	9.40	11.0	10.8	10.4
N16-9124	11.7	10.7	11.7	10.6	10.2
N16-9134	11.7	10.2	11.4	10.3	10.0
N16-9198	10.5	9.60	10.1	9.20	9.40
N7003CN	17.9	17.7	17.0	16.2	16.0
N94-7441	9.20	8.40	8.90	8.70	8.60
NC-Wilder	16.0	14.0	16.7	16.0	17.1
SC17-5537RR2	16.7	15.8	16.4	15.5	16.2
Mean	14.5	13.4	14.5	13.6	13.4
LSD (0.05)	0.80	1.00	1.70	1.10	1.70

Table 35. 2019 Southern Uniform Test Oil Means for Individual Varieties for MG V

Variety	Knoxville, TN	Pittsburg, KS	Portageville, MO	Tallassee, AL
	--------------------------	%	----------------------------	
Ellis	20.0	18.3	18.3	18.7
AG 53X6	20.6	18.3	18.7	19.0
JTN-5203	20.3	19.0	18.5	19.4
UA 5612	20.3	17.5	18.2	18.8
TN11-5140	20.5	18.1	18.2	19.1
AG 55X7	20.1	18.9	19.1	19.5
DA1134-015F	20.2	18.0	18.8	19.3
DA1239-09-L	19.8	18.0	18.3	18.8
K15-1809	19.3	17.6	17.4	19.3
N13-273	19.0	16.8	17.0	17.8
N16-590	20.3	17.8	17.8	19.1
N16-600	17.3	15.3	14.9	16.7
N16-8531	19.1	17.6	17.1	18.3
N16-8564	20.2	18.2	18.2	19.3
R13-13997	20.7	18.5	18.0	19.5
R14-898	20.5	18.1	18.6	19.7
R14-1422	19.9	16.7	17.7	19.3
R15-1194	20.6	18.6	19.3	20.4
R15-5695	21.5	19.2	19.9	21.0
S15-15809C	21.3	18.3	19.3	20.5
S15-17812C	20.9	19.2	19.1	20.5
S16-11651C	20.1	17.4	17.7	19.1
S16-15170C	20.6	17.8	18.9	19.3
S16-3739RY	20.7	18.4	18.8	19.6
S16-3747R	20.7	18.2	18.6	18.6
TN16-510R1	19.9	18.7	18.3	19.8
TN16-5027	19.9	17.9	18.2	18.2
V14-0079	20.5	18.6	18.9	19.9
V14-0153	20.0	17.1	17.6	17.5
V14-2421	19.7	17.0	17.2	17.4
V14-3821	20.0	18.1	18.2	19.8
V14-3983	19.8	18.6	18.1	.
Mean	20.1	18.0	18.2	19.1
LSD (0.05)	0.60	.	0.40	0.80

Table 36. 2019 Southern Uniform Test Oil Means for Individual Varieties for MG VI

Variety	Florence, SC	Plains, GA	Tallassee, AL
	-------------%	--------------	
AG64X8 RR2X	18.0	19.5	20.4
NC-Dunphy	20.3	20.4	20.5
NC-Dilday	21.3	20.9	20.6
CZ6316LL	20.5	21.0	20.7
G13-2842R2	17.7	19.3	18.7
G14-6063	20.3	20.6	20.6
G15-1038R2	17.7	18.9	19.8
G15-1811R2	17.1	19.7	19.7
G15-3361R2	17.3	19.3	18.8
G15-3606R2	19.7	20.8	20.0
G15PR-340	19.3	21.3	20.0
N08-105	20.9	21.3	21.1
N09-209	20.1	21.3	20.9
N10-7412	19.1	21.0	20.0
N11-9228	19.0	20.8	21.3
N11-9298	21.3	21.6	21.3
N16-9211	17.7	17.5	19.0
Mean	19.3	20.3	20.2
LSD (0.05)	0.90	0.80	0.90

Table 37. 2019 Southern Uniform Test Oil Means for Individual Varieties for MG VII

Variety	Athens, GA(A)	Athens, GA(B)	Florence, SC	Plains, GA	Tallassee, AL
			---------------------%---------------------		
AGS-738RR	.	.	.	.	.
AG74X8 RR2X	18.2	18.6	19.1	19.7	19.8
N7003CN	18.1	19.0	19.5	19.8	18.5
NC-Wilder	19.6	19.6	19.9	20.6	20.5
AGS 747LL	18.7	19.4	19.1	19.9	19.4
G14-2622R2	19.5	19.6	18.9	20.1	20.6
G14-4364R2	19.3	19.1	19.2	19.7	19.3
G15-2017R2	18.5	17.9	18.2	19.1	18.6
G15-2330R2	18.1	18.2	18.5	19.7	18.8
G15-2379R2	18.3	18.3	18.2	19.3	19.0
G15PRLL-989	19.4	19.8	19.9	20.1	20.9
N02-7834	17.8	17.9	18.3	18.8	19.2
N10-764	19.0	19.4	18.9	20.6	20.6
N10-792	19.5	19.3	19.6	20.3	20.5
N11-8098	17.6	18.7	18.2	19.5	20.5
N11-12528	17.8	17.9	17.7	18.9	18.4
N16-9134	17.4	17.1	16.5	17.1	17.2
N16-9198	16.9	17.1	17.2	16.8	17.7
N16-10425	18.3	17.8	18.3	18.9	19.1
N16-10554	18.3	18.1	18.0	18.7	18.8
N94-7441	17.1	16.7	16.9	17.2	17.5
SC17-5517RR1	18.8	19.4	19.0	20.7	20.1
SC17-5537RR2	17.9	18.5	18.8	19.6	19.1
Mean	18.4	18.5	18.5	19.3	19.3
LSD (0.05)	0.50	0.60	0.80	0.60	0.70

Table 38. 2020 Southern Uniform Test Oil Means for Individual Varieties for MG V

Variety	Belle Mina, AL	Knoxville, TN	Manhattan, KS	Plymouth, NC
	-----------------------------------%	-----------------------------------		
Ellis	18.4	19.0	17.1	18.4
AG 53X9	17.9	18.8	17.9	18.1
AG 55X7	18.3	19.7	18.6	18.7
TN09-008	19.5	20.0	18.3	19.0
TN11-5140	18.4	19.6	18.5	18.7
AG 56X8	17.9	19.1	17.6	18.2
DA1134-015F	18.7	19.4	17.9	18.5
DA13099-008F	19.4	20.0	17.6	18.5
K15-1809	18.8	18.4	17.5	18.0
N16-590	18.0	19.0	18.1	17.8
N16-8531	18.1	18.6	17.5	16.8
N16-8564	18.8	19.5	17.6	18.1
N17-2520	20.8	21.3	19.4	20.3
N17-882	18.0	18.7	18.2	17.8
NDPJE-14-194	19.1	19.5	18.0	18.6
NDPJE-14-217	18.4	19.3	17.9	18.3
Osage	17.5	18.1	17.0	18.0
R13-13997	18.6	19.7	18.0	19.5
R13-14635RR	18.5	19.5	17.6	18.4
R14-1422	18.4	18.5	16.6	18.4
R15-1587	19.0	19.4	17.2	18.7
S16-14801C	19.0	19.3	17.1	18.5
S16-14869C	18.6	19.7	17.6	19.1
S16-3739RY	19.4	19.8	17.2	19.3
S16-7840C	18.6	20.1	17.3	19.0
S16-9030C	19.0	19.3	17.9	19.1
S16-9090C	19.5	20.0	18.4	19.0
TN16-5024	18.9	19.0	16.6	17.9
V14-0079	18.8	19.8	18.2	18.7
V15-1815DI	19.6	20.0	18.7	19.0
V15-1872	18.8	18.7	17.2	17.8
V15-2261ST	19.4	18.8	18.8	18.2
V16-0709PR	19.1	20.0	17.8	19.3
Mean	18.8	19.4	17.8	18.5
LSD(0.05)	0.80	0.60	0.50	.

Table 39. 2020 Southern Uniform Test Oil Means for Individual Varieties for MG VI

Genotype	Athens, GA	Kinston, NC	Tallassee, AL
-----------------------%----------------------------			
AG64X8 RR2X	18.9	18.3	19.1
NC-Dunphy	19.6	19.4	19.6
NC-Dilday	19.9	19.8	19.9
CZ6316LL	20.2	18.6	20.2
G15-1038R2	18.0	16.7	18.2
G15-1811R2	19.2	18.1	18.7
G15-3361R2	18.0	17.1	17.8
G16-4162R2	18.4	18.2	18.3
G16-4995R2	17.7	16.6	17.4
G16-8779	18.5	17.9	19.2
G16LL-10015	19.4	18.9	19.7
N10-7412	19.3	18.3	19.3
N11-12528	18.3	16.9	17.5
N16-10756	18.6	16.8	17.3
N16-559	17.1	16.3	16.6
N16-8876	18.6	18.0	18.8
N16-9064	17.0	16.7	17.1
N16-9211	17.0	16.3	16.7
N16-D49-2524	19.4	18.6	20.4
N17-2535	21.5	20.8	21.4
Mean	18.7	17.9	18.6
LSD(0.05)	0.40	.	.

Table 40. 2020 Southern Uniform Test Oil Means for Individual Varieties for MG VII

Genotype	Athens, GA	Kinston, NC	Plains, GA	Plymouth, NC	Tallassee, AL
	-----------------------------------	-----------------------------------	%-----------------------------------	-----------------------------------	
AGS-738RR	19.5	18.2	19.2	17.7	19.1
AG74X8 RR2X	18.8	18.6	19.5	16.7	18.4
N7003CN	19.2	17.7	19.3	17.9	18.8
NC-Wilder	19.5	19.0	19.9	18.3	19.6
AGS 747LL	18.7	17.9	19.6	17.4	20.0
G15-2017R2	18.9	17.1	18.9	17.0	18.3
G15-2379R2	18.2	17.6	19.1	17.0	18.8
G16-4418R2	18.8	17.3	19.8	17.2	19.5
G16-5129R2	18.3	17.7	18.9	17.1	19.2
G16-5923R2	18.9	17.4	19.0	16.9	18.6
G16-5967R2	19.1	18.5	19.7	17.4	19.4
G16LL-10193	19.4	18.6	20.0	18.6	19.5
N16-10518	18.5	17.8	18.5	17.9	17.9
N16-10740	17.9	17.5	18.0	17.2	17.8
N16-9124	16.8	16.3	17.0	16.2	16.4
N16-9134	17.6	16.4	17.1	16.2	16.2
N16-9198	17.0	15.7	16.4	15.4	16.1
N94-7441	17.0	16.7	16.8	16.4	16.5
SC17-5537RR2	18.7	18.0	19.0	17.6	18.1
Mean	18.5	17.6	18.7	17.2	18.3
LSD(0.05)	0.40	.	0.40	.	.

Table 41. 2019 Southern Uniform Test Protein Means for Individual Varieties for MG V

Genotype	Knoxville, TN	Pittsburg, KS	Portageville, MO(A)	Tallassee, AL
-----------------------------------	-------------	%	-------------	-----------------------------------
AG 53X6	33.3	35.4	35.8	39.2
AG 55X7	35.1	36.1	35.6	38.5
DA1134-015F	34.1	34.7	36.2	38.5
DA1239-09-L	35.1	37.4	37.1	41.1
Ellis	33.8	35.9	35.9	38.1
JTN-5203	34.9	35.1	35.9	38.1
K15-1809	35.8	37.7	39	38.6
N13-273	38.7	40.7	40	41.3
N16-590	37.4	39.1	38.6	40
N16-600	39.5	41.6	41.9	41.8
N16-8531	36.4	37.4	38	40.3
N16-8564	35.5	36.8	38	39.4
R13-13997	34.1	36.9	37.7	37.2
R14-1422	34	37.4	36.6	38.2
R14-898	33.1	36.5	36.5	38.3
R15-1194	33.4	35.5	34.4	36.7
R15-5695	33.7	35.8	35.4	36.7
S15-15809C	33.8	35.5	35.5	37.8
S15-17812C	36.5	36.8	37.9	39.8
S16-11651C	34.2	35.8	36.9	37.4
S16-15170C	33.9	36.1	36.6	38.5
S16-3739RY	33.8	34.9	36.3	38.5
S16-3747R	32.8	33.6	35.8	38
TN11-5140	34.4	36.6	37.4	37.7
TN16-5027	32.8	35.2	35.8	37.5
TN16-510R1	34.3	35.3	35.7	36.5
UA 5612	34.3	37.9	36.6	38.9
V14-0079	36.4	37	37.6	40.3
V14-0153	36.6	38.9	39	40.8
V14-2421	36.9	39.8	39.4	42.4
V14-3821	36.2	37.1	38.1	38.3
V14-3983	35.2	36.2	37.9	.
Mean	35	36.8	36.2	38.8
LSD (0.05)	1.20	.	1.20	1.60

Table 42. 2019 Southern Uniform Test Protein Means for Individual Varieties for MG VI

Genotype	Florence, SC	Plains, GA	Tallassee, AL
	------------------------%-------------------		
AG64X8 RR2X	37.7	35.9	34.9
NC-Dunphy	35.1	35.5	34.5
NC-Dilday	34.4	35.2	35.4
CZ6316LL	34.2	34.1	34.9
G13-2842R2	37.7	36.1	37.4
G14-6063	37.3	36.6	35.9
G15-1038R2	38.8	37.5	36.6
G15-1811R2	37.9	35.4	35.5
G15-3361R2	38.4	36.2	36.8
G15-3606R2	36.9	37.4	36.7
G15PR-340	37.1	34.4	37.2
N08-105	35.8	35.0	34.6
N09-209	35.7	33.5	34.5
N10-7412	36.2	35.5	35.9
N11-9228	37.7	36.5	34.5
N11-9298	34.5	35.4	34.3
N16-9211	38.8	39.1	37.8
Mean	36.7	35.8	35.7
LSD (0.05)	1.50	1.10	1.50

Table 43. 2019 Southern Uniform Test Protein Means for Individual Varieties for MG VII

Genotype	Athens, GA(A)	Athens, GA(B)	Florence, SC	Plains, GA	Tallassee, AL
	--	-------%-------	--		
AGS-7389RR	.	.	.	.	.
AG74X8 RR2X	37.1	36.3	36.5	35.9	35.9
N7003CN	36.0	36.4	35.7	35.5	38.1
NC-Wilder	35.8	35.2	35.5	34.3	36.3
AGS 747LL	36.0	35.3	36.7	35.4	37.3
G14-2622R2	35.1	35.1	36.1	34.6	35.5
G14-4364R2	33.8	34.9	35.5	34.4	35.8
G15-2017R2	36.1	36.7	36.6	36.1	37.3
G15-2330R2	37.2	37.3	37.4	35.8	37.8
G15-2379R2	37.6	37.6	37.6	35.9	37.4
G15PRLL-989	35.7	35.6	35.8	34.6	34.9
N02-7834	38.3	38.0	38.1	36.9	37.9
N10-764	37.0	36.8	37.3	34.7	35.5
N10-792	36.6	36.3	36.6	36.1	35.6
N11-8098	38.9	37.4	39.0	36.5	37.2
N11-12528	39.0	39.0	38.9	37.1	38.5
N16-9134	38.2	38.2	39.6	38.5	39.8
N16-9198	38.2	37.9	39.1	38.7	39.1
N16-10425	37.4	37.7	37.3	36.9	37.4
N16-10554	37.9	37.7	38.2	36.9	38.4
N94-7441	38.1	38.3	38.8	38.4	38.5
SC17-5517RR1	35.9	34.7	36.7	34.4	35.5
SC17-5537RR2	37.0	36.8	37.0	35.9	37.6
Mean	37.0	36.8	37.3	36.1	37.1
LSD(0.05)	1.10	1.20	1.30	1.00	1.20

Table 44. 2020 Southern Uniform Test Protein Means for Individual Varieties for MG V

Genotype	Belle Mina, AL	Knoxville, TN	Manhattan, KS	Plymouth, NC
	----------	---------- %	----------	----------
Ellis	36.7	35.8	33.6	35.8
AG 53X9	37.6	35.7	33.0	36.5
AG 55X7	37.3	35.1	32.8	35.5
TN09-008	34.2	33.3	30.7	33.7
TN11-5140	36.8	34.9	33.2	34.8
AG 56X8	37.1	34.9	32.3	36.1
DA1134-015F	37.4	34.9	32.8	34.1
DA13099-008F	35.1	34.8	33.6	36.5
K15-1809	37.5	37.3	34.8	38.7
N16-590	39.8	35.9	35.6	38.3
N16-8531	38.2	36.2	34.0	38.9
N16-8564	37.7	36.4	34.2	37.7
N17-2520	36.0	34.2	32.7	35.6
N17-882	40.2	39.4	35.9	39.8
NDPJE-14-194	35.8	35.4	33.6	36.1
NDPJE-14-217	37.3	35.8	33.9	36.9
Osage	39.8	37.9	35.7	38.1
R13-13997	36.8	35.5	32.9	35.8
R13-14635RR	36.5	35.0	32.9	35.7
R14-1422	36.2	36.1	34.1	35.2
R15-1587	35.7	35.3	33.4	35.2
S16-14801C	36.1	35.6	33.1	35.8
S16-14869C	36.3	34.9	32.2	35.2
S16-3739RY	36.2	34.6	32.7	35.5
S16-7840C	35.9	33.6	32.4	34.8
S16-9030C	36.2	35.8	31.8	34.7
S16-9090C	35.9	34.4	31.9	34.9
TN16-5024	34.6	34.3	33.1	35.2
V14-0079	37.9	37.0	34.5	38.1
V15-1815DI	35.8	35.1	32.7	35.7
V15-1872	36.4	35.9	33.3	36.7
V15-2261ST	37.2	37.4	33.3	37.7
V16-0709PR	36.4	34.9	32.5	34.9
Mean	36.8	35.6	33.3	36.2
LSD(0.05)	1.10	1.20	1.10	.

Table 45. 2020 Southern Uniform Test Protein Means for MG VI

Genotype	Athens, GA	Kinston, NC	Tallassee, AL
	---------------------------------------%	--	
AG64X8 RR2X	34.9	36.0	34.4
NC-Dunphy	34.5	34.6	34.4
NC-Dilday	33.9	34.3	33.8
CZ6316LL	32.9	35.1	33.5
G15-1038R2	36.3	39.8	37.0
G15-1811R2	34.4	36.5	36.2
G15-3361R2	36.0	37.1	36.2
G16-4162R2	35.2	36.6	36.5
G16-4995R2	37.2	39.0	37.7
G16-8779	35.2	36.3	35.0
G16LL-10015	35.1	36.2	35.0
N10-7412	34.9	37.1	34.9
N11-12528	36.7	38.5	38.4
N16-10756	36.3	38.6	37.3
N16-559	40.7	42.8	42.1
N16-8876	36.8	38.6	36.1
N16-9064	36.9	37.1	36.5
N16-9211	38.5	39.6	39.4
N16-D49-2524	37.0	37.6	35.8
N17-2535	33.8	35.0	35.0
Mean	35.9	37.3	36.3
LSD(0.05)	1.10	.	.

Table 46. 2020 Southern Uniform Test Protein Means for Individual Varieties for MG VII

Genotype	Athens, GA	Kinston, NC	Plains, GA	Plymouth, NC	Tallassee, AL
	-------------------	-------------------	%	-------------------	
AGS-738RR	34.0	35.3	34.8	34.8	35.0
AG74X8 RR2X	34.7	34.6	34.5	37.3	35.7
N7003CN	34.3	36.6	34.2	35.1	36.2
NC-Wilder	34.6	34.4	34.6	35.4	35.3
AGS 747LL	35.5	36.0	35.4	36.1	35.1
G15-2017R2	34.6	37.1	35.3	36.9	37.2
G15-2379R2	36.2	36.3	34.7	36.3	36.6
G16-4418R2	35.2	36.6	35.0	36.5	35.8
G16-5129R2	34.9	36.4	35.0	36.5	35.1
G16-5923R2	34.9	37.3	35.4	36.4	36.8
G16-5967R2	33.3	34.5	31.6	35.1	33.9
G16LL-10193	34.6	36.3	34.4	35.7	36.9
N16-10518	35.9	36.6	35.9	37.1	37.7
N16-10740	37.6	37.2	37.5	38.3	38.1
N16-9124	38.7	38.8	38.6	38.8	39.0
N16-9134	37.5	38.4	38.0	38.7	38.9
N16-9198	36.9	38.9	38.4	39.2	39.0
N94-7441	37.1	37.2	37.3	38.1	38.4
SC17-5537RR2	35.4	36.0	35.9	37.2	36.9
Mean	35.6	36.5	35.6	36.8	36.7
LSD(0.05)	0.90	.	1.00	.	.

Appendix 2.

Figure 1. Regression between Perten and Volumetric Instruments

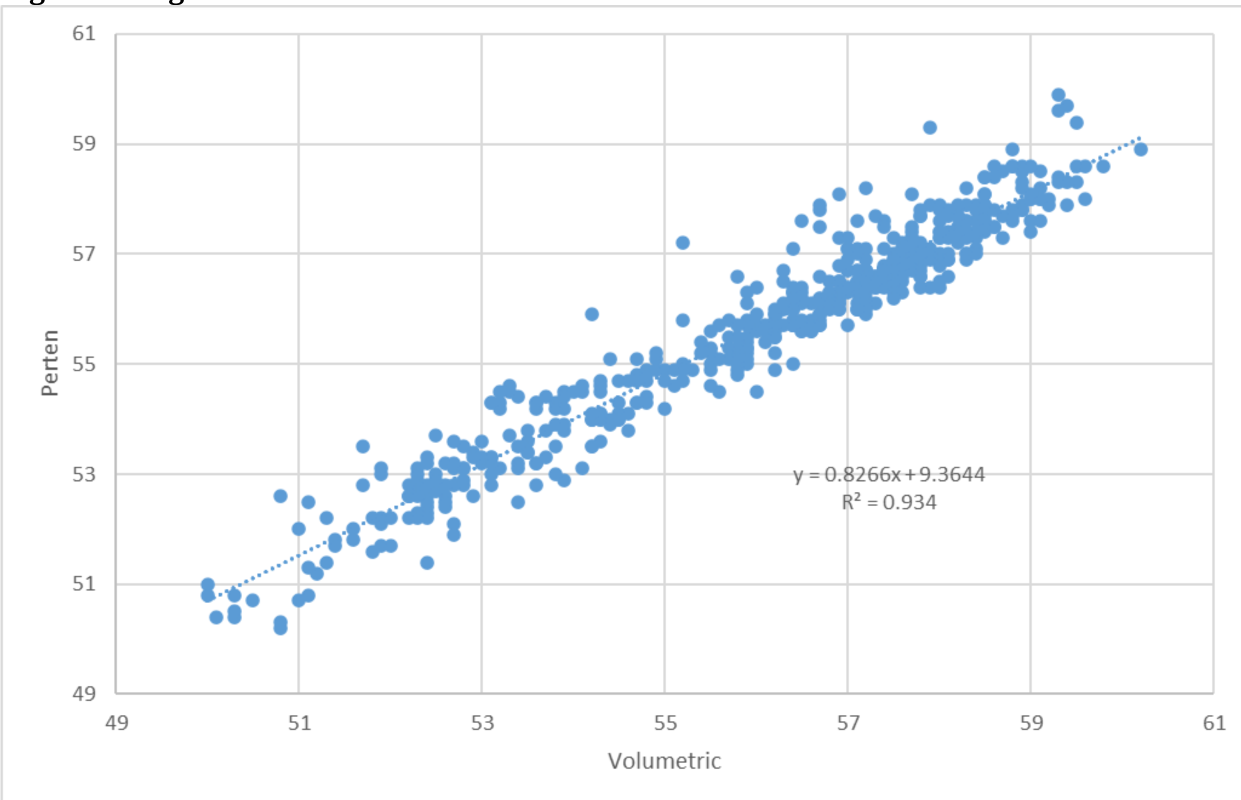

Figure 2. Regression between GAC and Volumetric Instruments

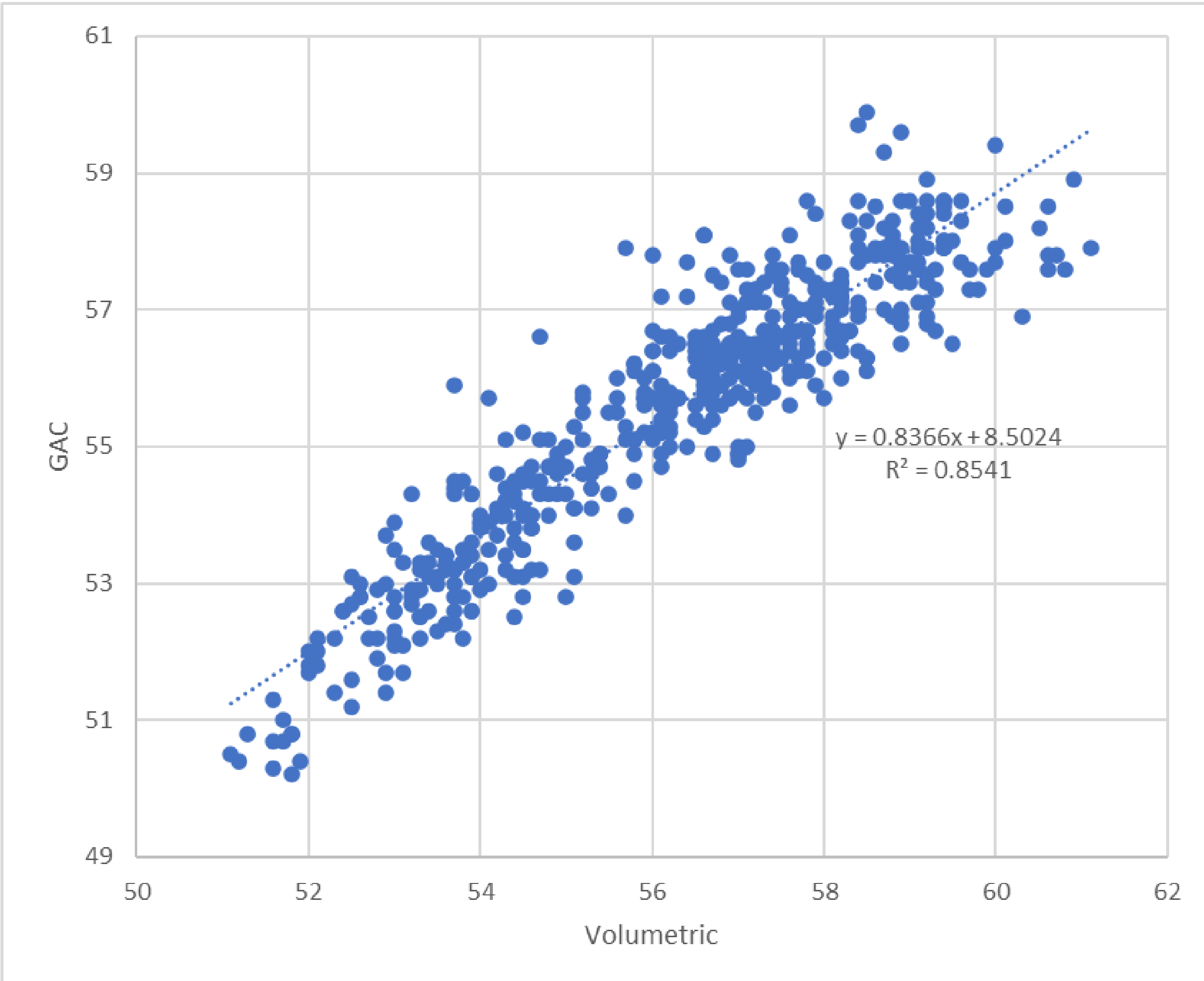

Figure 3. Regression between GAC and Perten Instruments.