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ENGINEERING AND GINNING

The Classification of Cotton

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ABSTRACT

Cotton classification is the process of using official standards and standardized procedures to measure the physical attributes of raw cotton. The USDA Agricultural Marketing Service (AMS) classes essentially all cotton grown in the U.S. Samples are collected from each bale at the gin or warehouse for classing at one of 10 AMS classing offices. Automated instrumentation is used to assess fiber length, length uniformity, strength, color, micronaire, and non-lint content. Automation has allowed AMS to continue classing cotton efficiently as crop size has expanded. A human classer examines every classing sample to determine if there is any extraneous matter present that would alter the value of the bale. Classing results are matched with a permanent bale identification number that is assigned to each bale at the time of sampling. This identification number allows the bale to be identified throughout the supply chain, from packaging of the bale at the gin through consumption on the textile mill floor.

The United States Department of Agriculture (USDA) Agricultural Marketing Service (AMS) Cotton and Tobacco Program classes (grades) essentially all cotton grown in the U.S. Following ginning, each bale is sampled from opposite sides of the bale, to represent the first and last cotton coming from the bale press. The bale sample (Fig. 1), with a total weight of approximately 0.23 kg (0.5 lbs), is identified with a Permanent Bale Identification (PBI) tag. The samples are collected routinely from individual gins or warehouses and delivered for testing to a USDA cotton classing facility. Once received at the classing facility, the samples are placed into perforated plastic containers and conditioned until the moisture content (dry basis) is 6.75 to 8.25%. The conditioned samples are then subjected to physical testing by high volume instruments (HVI®, Fig. 2) and a visual inspection by a cotton classer.

Figure 1. Cotton classification bale samples containing plastic contamination.

Figure 2. Typical HVI 1000 instrument used in cotton classification.

The USDA cotton classification system has transformed from reliance on human senses to use of precision instruments that analyze more quality factors with greater accuracy. Since 1991, every sample delivered to USDA for cotton classification has been instrument tested. The instrument provides cotton quality measurements for

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micronaire, fiber length, length uniformity index, fiber strength, color reflectance (Rd), color yellowness (+b), color grade, trash percentage area, trash particle count, and leaf grade. Prior to HVI, USDA cotton classers determined fiber staple length, color grade, leaf grade, and identified the presence of extraneous matter. Over the years, developments in testing technology have resulted in a migration of cotton classification factors from the human classer to the instrument. The migration from classer to instrument began with fiber staple length in 1991, followed by color grade in 2000 and leaf grade in 2011. Today, only the identification of extraneous matter and special conditions are provided by the human classer.

For the USDA to carry out the cotton classification process efficiently on millions of samples each year, a high degree of automation is required. Upon arriving at the classing office, samples are conditioned at environmental conditions consisting of a temperature of 21° C ± 1° C (70° F ± 2° F) and relative humidity of 65% ± 2% to allow the fiber moisture content to reach an equilibrium (ASTM, 2020). Conveyance systems automatically move the samples through the processes of receiving, moisture conditioning, and testing. The instrument systems used in the classification process combine the individual classification measurements into an integrated measurement system. As samples move through the measurement systems, minimal human interaction is required. As automation continues to advance in the whole cotton classification process over time, the efficiency and accuracy of cotton classification are expected to continue increasing.

Permanent Bale Identification Tag. The U.S. cotton industry uses the PBI tag as part of a system that enables a unique number and barcode to accompany every bale from the gin to the textile mill. Since 1997, the PBI system has used a 12-digit unique identifier that consists of a five-digit gin code and a seven-digit bale number. The seven-digit bale number is not repeated within a five-year period. The PBI is presented using a standard tag format that includes the PBI in both an eye-readable and a Code 128 subset C barcode format (Fig. 3). The PBI tag also includes multiple coupons with the required information for accompanying classing samples from the gin to the classing office and for use by the textile mill (National Cotton Council, 2020).

Figure 3. Sample of permanent bale identification tag.

USDA INSTRUMENT DETERMINATIONS

Fiber Length. Fiber length is measured by passing a small tuft of paralleled fibers known as a beard through an optical scanner within the instrument system. The beard is formed by grasping the fibers with a needle comb and using mechanized combing and brushing to make the fibers parallel (Hertel, 1940). Fiber length is reported for the average length of the longer half of the fibers (upperhalf mean length). Fiber length is reported to the nearest 100th of an inch. Staple length is also reported and is the upper-half mean length converted to 30-seconds of an inch.

Fiber length is largely a varietal characteristic, although aggressive handling of the cotton can reduce the length (Anthony and Bragg, 1987; Williford, 1992). Fiber length also can decrease due to excessive heat during the early stages of fiber development or when moisture is limited (Constable et al., 1976; Gipson and Ray, 1969). General classifications of possible upper-half mean length values are shown in Table 1 (Cotton Incorporated, 2019).

Table 1. Interpretation of upper-half mean length values

Upper-Half Mean Length inches	Upper-Half Mean Length mm	Rating
> 1.26	> 32.0	Extra Long
1.11-1.26	28.2-32.0	Long
0.99-1.10	25.1-28.2	Medium
< 0.99	< 25.1	Short

Length Uniformity Index. Length Uniformity Index is the ratio of the average, or mean, length of the fibers to the upper-half mean length (fiber length) and is expressed as a percentage. Length uniformity index is calculated by the same optical scan used for the upper-half mean length measurement.

If all fibers in a cotton sample were the same length, the length uniformity index would be 100%. However, because cotton is a natural fiber with length variations among fibers, cotton length uniformity will always be less than 100%. Length uniformity index is not a measurement of short fiber content, which is the percentage of fibers less than 12.7 mm (0.5 in); however, a lower uniformity index often is associated with an increase in short fiber content (Ramey and Beaton, 1989). Uniformity index reflects the influence of both variety (Smith et al., 2010) and processing (Anthony and Bragg, 1987). Roller ginning will result in an increase in length uniformity compared to saw ginning the same cotton (Armijo and Gillum, 2010). Table 2 provides guidance on the meaning of length uniformity for cotton (Cotton Incorporated, 2018).

Table 2. Interpretation of length uniformity index values

Length Uniformity Index (%)	Rating of Length Uniformity
85	Very High
83-85	High
80-82	Average
77-79	Low
< 77	Very Low

The presence of short fibers, or those fibers less than 0.5 inch in length, adversely affects the utility and quality of cotton. Most short fibers are removed as waste in textile processing. Short fibers that do not get removed as waste tend to aggregate during the yarn spinning process causing thick places in yarn. Yarns with thick places are non-uniform and cannot be used in highquality fabrics. Additionally, thick places frequently result in points of weakness in yarns that cause disruptions in yarn processing known as ends down (Delhom et al., 2017).

When fibers are removed from the seed in ginning, some fibers break at a point other than near the seed coat and can be removed in two or more pieces. Lint cleaners and other gin machinery also contribute to fiber breakage. Proper setting of machines in the gin will minimize fiber breakage, thus improving fiber length and length uniformity. Other factors affecting length uniformity are fiber maturity and fiber strength. Immature fibers have less resistance to breakage than mature fibers, and weak fibers have less resistance to breakage than strong fibers (Anthony and Bragg, 1987).

Fiber Strength. Fiber strength is determined by the instrument on the same beard of fibers used for the length and length uniformity index measurements. Fiber strength is obtained by tightly clamping the beard and applying tension until the fibers break. Strength results are reported in grams-force per tex. A tex is equal to the weight in grams of 1,000 meters of fiber. The strength reported is the maximum force in grams required to break a onetex bundle of fibers. The results from the length test inform the instrument as to where exactly to clamp the fiber bundle to ensure the proper mass of fibers is being tested (Naylor et al., 2014). The relative ranking of strength values is provided in Table 3 (Cotton Incorporated, 2018). Fiber strength is largely a function of genetics and growing environment (Gannaway, 1982; Meredith, 2005; Paterson et al., 2003). Although ginning cannot directly alter fiber strength, fiber strength can influence fiber quality due to damage during processing (Dever et al., 1988). The conditioning of samples prior to testing ensures consistent and repeatable results of strength testing as higher moisture content will result in higher strength values and lower moisture content can result in artificially lower strength values.

Table 3. Interpretation of strength values

HVI Strength (g/tex)	Rating of Strength
≥ 31	Very Strong
29-30	Strong
26-28	Average
24-25	Intermediate
≤ 23	Weak

Micronaire. Micronaire is an indirect measure of the fineness and maturity of a cotton sample. The measurement is performed by an airflow instrument that measures the permeability of cotton by passing compressed air through a compressed cotton specimen of fixed weight and fixed volume. The airflow permeability through the cotton specimen is expressed as the micronaire. Cottons with high micronaire are coarse, with fewer fibers per unit weight resulting in less fiber surface area allowing air to pass through with less resistance. Low micronaire cottons, on the other hand, are fine and have more fibers per unit weight, providing more surface area resulting in more resistance to airflow. The importance of micronaire to a textile mill is reflected in the application of premiums or discounts to the price of cotton based on micronaire values (Table 4) (Cotton Incorporated, 2018).

Table 4. Interpretation of micronaire values

Micronaire	Loan Classification of Micronaire
≥ 5.0	Discount Range
4.3-4.9	Base Range
3.7-4.2	Premium Range
3.5-3.6	Base Range
≤ 3.4	Discount Range

For a given variety, cotton fibers with lower micronaire values are immature and lack adequate thickening of the fiber wall. Immature fibers can cause reduced dye uptake, increased fiber breakage, increased nep formation, and higher textile manufacturing waste (Anthony et al., 1988). Overly mature cotton fibers will have a high micronaire value and possess excessive fiber wall thickening. These fibers are limited in use to lower quality coarse yarns such as denim yarn due to their high degree of coarseness (Delhom et al., 2017).

Fiber fineness is a varietal characteristic but is also affected by growing conditions in the latter stages of fiber development (Hessler, 1961). Favorable growing conditions result in fully mature fibers and optimum micronaire readings. Unfavorable conditions, such as lack of moisture, early freeze, or any other conditions that interrupt plant processes, will result in immature fibers and low micronaire readings. High micronaire is generally caused by excess carbohydrates in the plant resulting in thick layers of cellulose in the fiber. This is often caused by shedding of smaller, less mature bolls due to hot weather and water stress. The more mature bolls left behind on the plant will have excessive carbohydrates available due to fewer bolls on the plant resulting in excess cellulose deposits in the fibers (Ramey, 1986).

Color. Instrument-determined cotton color is measured in percentage reflectance (Rd) and yellowness (+b). Reflectance indicates the brightness or grayness of the sample and is usually within the 48 to 86 range. Yellowness indicates the amount of yellow coloration in the sample and is usually within the 6 to 17 range.

Cotton fiber color is affected to a great extent by weather and length of exposure to weather conditions after the bolls open. It also can be affected by varietal characteristics and by harvesting and ginning practices. When Upland cotton opens normally, it has a bright, white color. Abnormal color indicates a deterioration in quality. Continued exposure to weather and the action of microorganisms can cause the white cotton to lose its brightness and become darker in color. Excessive rainfall received after boll opening but prior to harvest can cause tannins to leach out of carpal (boll) segments and into the fiber producing a spotted or tinged color grade. When plant growth is stopped prematurely by frost, drought, or other weather conditions, cotton can have a yellow color that varies in intensity. Cotton can also become yellowed or yellow-spotted by insects or moisture-related microorganism activity prior to ginning (Hake et al., 1996). Ginning does not have a significant effect on actual fiber color. The removal of non-lint content and combing of fibers during lint cleaning can alter the perceived color. The blending and combing action of lint cleaning can reduce the incident of “spotted” color bales.

Color Grade. The color grade in USDA cotton classification is derived from the Rd and +b measurements described in the previous section. The relationship between Rd and +b color measurements and the color grades are illustrated in the Upland and American Pima color charts (Figs. 4 and 5, respectively). There are a total of 25 Upland color grades and six American Pima color grades. There are also five below-grade designations for Upland cotton designated as grades 81-85 on the color chart. Fifteen of the Upland and all six of the American Pima color grades are represented as standards in physical form by samples prepared annually by USDA. The remaining standards for the Upland color grades are descriptive. Each descriptive standard provides a description for cotton that lies above, below, or between certain physical standards. Copies of the physical standards are prepared and sold to the U.S. and international cotton industries as a visual reference.

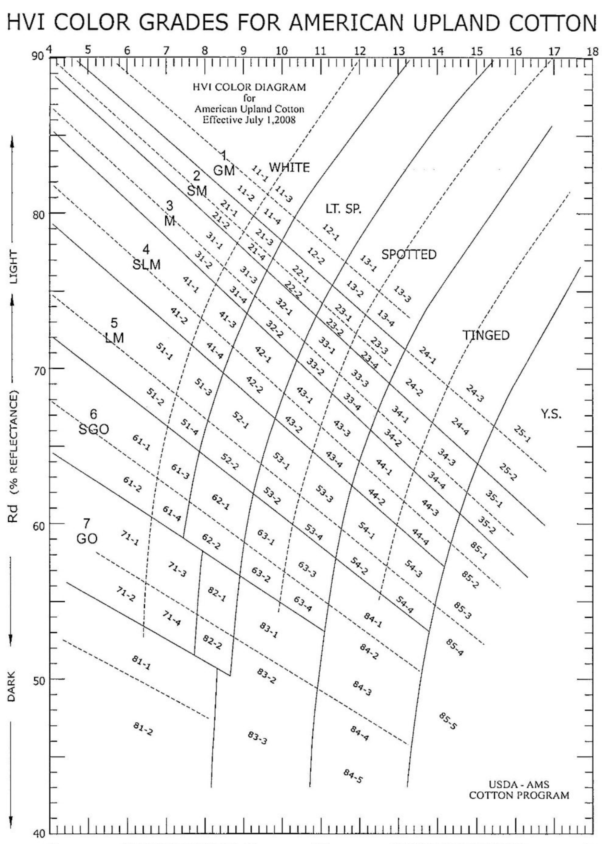

Figure 4. Official cotton color chart for American Upland cotton (courtesy of USDA, Agricultural Marketing Service, Cotton & Tobacco Program).

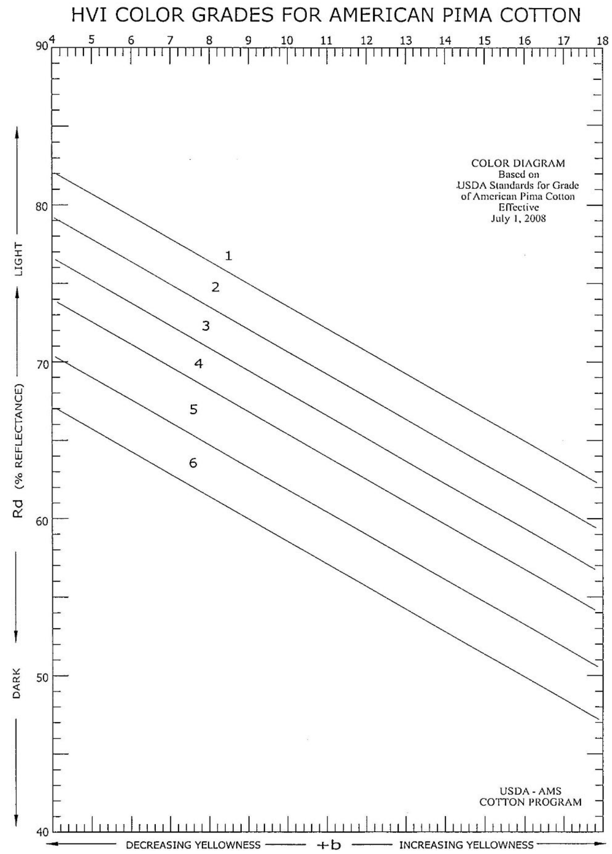

Figure 5. Official cotton color chart for American Pima cotton (courtesy of USDA, Agricultural Marketing Service, Cotton & Tobacco Program).

The range of each color grade for which there is a physical standard is represented by six samples placed adjacent to each other in a grade standards box (Fig. 6). For practical considerations, the color and leaf grade standards are contained in the same box. For example, the standards box containing the Strict Low Middling (41) color grade also contains the size and amount of leaf that would be described as leaf grade 4.

Figure 6. Upland (left) and Pima (right) cotton standard boxes (courtesy of Cotton Incorporated).

Although modern color grades are derived from Rd and +b measurements, the origin of the color grades dates to the 1800s. Cotton merchants in Liverpool, England were using the terms Good and Fine, Good Fair, Fair, Middling, and Ordinary by

1825. In 1874, a group of American cotton exchange representatives adopted a "Standard American Classification" consisting of five grades: Good Middling, Middling, Low Middling, Good Ordinary, and Ordinary (Nickerson and Griffith, 1964). These terms are still in use with the modern color chart.

American Pima and Upland grade standards differ. American Pima cotton has a deeper natural yellow color than Upland cotton. The leaf content of American Pima standards is unique to this cotton and does not match that of the Upland standards. The preparation is different from the preparation for Upland standards, because American Pima cotton is normally ginned on roller gins and appears stringy and rough. Upland cotton is usually cleaned with sawtype lint cleaners that produce a smooth, blended, combed sample. Roller ginned cotton is usually cleaned with an air or cylindertype cleaner and is rough in appearance.

Trash. Instrument-determined cotton trash is measured in trash percentage area and trash particle count. The trash content measured by the instrument is determined by scanning the sample surface and measuring the non-lint particles present. The trash percentage area is the percentage of the scanned surface covered by non-lint particles, and the trash particle count is the number of particles on the scanned surface.

Leaf Grade. Leaf grade describes the amount of leaf content in cotton. There are seven leaf grades for Upland cotton and six leaf grades for American Pima cotton. All leaf grades are represented as part of the physical color grade standards explained in the Color Grade section. Leaf grade in USDA cotton classification is derived from the instrument trash measurements of trash percentage area and trash particle count described in the Trash section.

In the textile spinning industry, leaf material is viewed as waste and adds an additional cost factor associated with its removal. Leaf content is affected by leaf characteristics, harvesting methods, and harvesting conditions. The proper application and timing of harvest aids is an important factor in minimizing leaf content of seed cotton and consequently ginned lint. The amount of leaf material remaining in the lint after ginning depends on the amount present in the seed cotton before ginning and on the type and amount of cleaning and drying equipment used during ginning (Mangialardi, 1993). Even with the most careful harvesting and ginning methods, a small amount of leaf will remain in the cotton lint. Although, in general, the higher the leaf grade, the more non-lint content present, it is not a direct relationship as some types of non-lint content are denser than others. The average trash percentage area for the seven leaf grades of Upland cotton demonstrates a nonlinear relationship, as shown in Table 5 (Townsend, 2005). It should be noted that the data in Table 5 are not necessarily valid with modern varieties, harvesting systems, and ginning practices.

Table 5. Average relationship between leaf grade and percent area of trash[z]

Leaf Grade	Average Percent Area of Trash (%)
1	0.12
2	0.20
3	0.33
4	0.50
5	0.68
6	0.92
7	1.21

[z] **Data cited are from Townsend, 2005 and might not be representative of modern practices.**

USDA CLASSER DETERMINATIONS

Every classing sample is reviewed by a human classer for classer determinations. The classer performs several "breaks" of the classing sample in which various surfaces of the sample are exposed for examination. The classer inspects the sample for extraneous matter, including the condition of the sample to represent issues such as preparation and spindle twist. These "classer calls" are issued a code and level when observed, and a level 2 call is more severe than a level 1. An option for "other" exists for any issues observed by the classer that are not covered by a category. A sample might only have one classer call, so if multiple conditions exist, the most significant is reported by the classer. The extraneous matter codes for classer determinations are shown in Table 6.

Extraneous Matter. Extraneous matter is determined by the human classer and is defined as any substance in a cotton sample that is not cotton fiber or leaf material. Examples of extraneous matter are bark, grass, seed coat fragments, spindle twist, dust, oil, and plastic. When extraneous matter is prevalent in a sample, a notation will be made by the classer in the classification data for that cotton sample. For most conditions, a single piece of foreign matter will not result in the call, as there must be a significant amount of the material to make note of. An exception exists for plastic, where even a single piece of material will necessitate the call. As of the 2018 crop, classer calls of 71 and 72 were added specifically for plastic contamination. Plastic contamination is not like plant-based extraneous matter and is unlikely to be uniformly distributed through the bale. A plastic contamination call supersedes all other calls and cannot be replaced by re-classing the sample.

Table 6. Extraneous matter codes

Code	Condition
01	Preparation, Level 1
02	Preparation, Level 2
11	Bark, Level 1
12	Bark, Level 2
21	Grass, Level 1
22	Grass, Level 2
31	Seed Coat Fragments, Level 1
32	Seed Coat Fragments, Level 2
41	Oil, Level 1
42	Oil, Level 2
51	Spindle Twist, Level 1
52	Spindle Twist, Level 2
61	Other, Level 1
62	Other, Level 2
71	Plastic, Level 1
72	Plastic, Level 2

Preparation. Preparation is determined by the human classer and is a measure of the degree of roughness or smoothness of the ginned cotton lint. Preparation is noted under extraneous matter and it indicates the appearance of abnormal preparation of the cotton. Generally, smooth cotton has less spinning waste and produces a smoother and more uniform yarn than rough cotton. The rough appearance of cotton with preparation is usually indicative of issues with excessive moisture prior to ginning (Griffin and Merkel, 1953). Variations in methods of harvesting and ginning can produce differences in appearance and preparation but will not, by themselves, result in a preparation call. When rough preparation is present in a cotton sample, a notation for that sample will be made by the classer in the classification data.

Special Conditions. In certain special cases, a human classer can observe a special condition that results in the replacement of the color grade with a special condition code because these conditions negate the accuracy of the color grade. The special conditions that warrant a code include a mixture of Upland and Pima cotton in the same bale or the observation of damage from either fire or water. The use of these codes is rare.

SUMMARY

The USDA AMS classifies virtually all cotton grown in the U.S. USDA has adopted increasingly automated testing over the past three decades. Essentially every bale produced in the U.S. is sampled at either the gin or warehouse. The bale samples are transported to an AMS classing office for conditioning and testing. Automated testing equipment allows for rapid, accurate, and repeatable determination of quality factors such as fiber length, strength, micronaire, color, and leaf grade. A human classer still examines every physical sample of cotton for extraneous matter. The unique PBI assigned to a bale at the time of sampling is maintained until the bale is consumed at the textile mill and is permanently linked to the information generated by the classing office.

DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA. The USDA is an equal opportunity employer.

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