ACCURACY OF ALTERNATE OVEN DRYING PROCEDURES

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Abstract

Cotton post-harvest processing research frequently requires moisture content determination for seed cotton, cotton seed, and cotton lint. Standard procedures documented in 1972 and currently practiced were analyzed to estimate measurement uncertainty. Understanding the source and magnitude of errors will aid in increasing precision and interpreting results. Four seed cotton varieties (9.4 to 36.8% foreign matter) and one variety of lint were stored for more than 30 days in a controlled environment (21 C, 65% RH) and thoroughly blended to reach uniform moisture content. Drying baskets (652 cc) were loaded, in random order, with 25, 35, 50, 71 and 100 grams of material; wet weights were determined in the controlled environment. Additional samples were placed in plastic zipper bags and sent by air freight or stored on-site. Replicated sets of seed cotton and lint samples were weighed inside a drying oven, then outside of it while still hot. Some samples were dried for twice the recommended time. Sample location in the ovens was tracked. Weighing hot dry samples outside of the drying oven increased apparent moisture content approximately half of one percent due to buoyancy. Smaller differences in apparent moisture content were found when halving or doubling the amount of material in drying baskets, or doubling the drying time. Foreign matter had a minor influence on apparent moisture content. Storage for three days and shipping by airfreight in plastic zipper bags did not measurably change the apparent moisture content. Sample location within the drying oven made no difference.

Introduction

The physical properties of commercial cotton cultivars (G. hirsutum and G. barbadense) are sensitive to moisture content, necessitating accurate quantification of this variable during research. Procedures to determine the moisture content of seed cotton, lint, and cottonseed were developed by the U.S. Cotton Ginning Laboratory in Stoneville, Mississippi, written by Cotton Technologist Jacob Shepherd, and published by the U.S. Government Printing Office (Shepherd 1972). This method for lint, with minor variation, was formalized and published as a standard by the American Society for Testing and Materials as ASTM-D2495 (ASTM 2001). A similar standard was published by the American Association of Textile Chemists and Colorists as AATCC-20A (AATCC 2002). The AATCC standard did not require fan-forced ventilation of the drying oven. ASTM and AATCC have since coordinated their standards to avoid redundancy (Montalvo and Von Hoven, 2008). In current research settings these procedures are not followed exactly, as slight modifications have been introduced for various reasons. Mechanical balances have been replaced by electronic ones that have an order of magnitude greater precision. Innovations such as plastic food storage bags with integral zippers (Byler, 2004), quart-sized all-plastic paint cans, and nation-wide express air freight have also impacted research practices. The biggest change in lab practices is using high-capacity ovens and weighing hot, dry samples outside of the oven.

This experiment was designed to answer six key questions:

- What impact on moisture content estimate does weighing outside of the oven have compared to weighing inside the oven?
- How much does sample initial weight influence the estimate of moisture content?
- How sensitive is the moisture content estimate of seed cotton to foreign matter content?
- How much does excess drying time change the estimated moisture content?
- What errors are introduced by different sample shipping and storage practices?
- Is there any difference in estimated moisture content caused by the sample's location in the drying oven?

The first two questions were explored with grade 0000 steel wool as well as with seed cotton and lint. Note that these trials examine the precision of moisture content estimates and the sources of errors at the laboratory level. They do not address the accuracy of these methods. As emphasized by Shepherd (1972), and, as is still the case today, "…no justifiable statement on accuracy can be made because the *true value* of moisture content cannot be established by any accepted reference method." For this reason, the term "Apparent Moisture Content" is used when discussing results from these trials.

While the true moisture content remains an unknown quantity, we assume that the materials tested in this set of experiments were initially at the same moisture content because they were stored for a long time at the same temperature and relative humidity. The equilibrium moisture contents for seed cotton, lint and cottonseed are different, but they are each a function of ambient conditions.

Materials and Methods

Seed cotton, cottonseed, and lint were thoroughly blended and stored in a controlled environment of 21 C (70 F) and 65% relative humidity for more than 30 days to equilibrate to a uniform moisture content. The four types of seed cotton used, representing current varieties and harvest practices, were, in order by increasing trash content: a spindle harvested upland (Dyna-Gro 3385, Crop Production Services, Loveland, CO), a spindle harvested Pima (Deltapine 340, Monsanto Co., St. Louis, MO), a stripper harvested upland (Deltapine 1219 B2RF) with field cleaning, and a stripper harvested upland (Stoneville 5458 B2RF, Bayer, Leverkusen, Germany) without field cleaning (Figure 1). Trash content was determined using the pneumatic fractionation method (Shepherd 1972). Cottonseed came from one Pima and three upland experimental varieties, and the lint was an upland variety (Dyna-Gro 3385).

Figure 1. Seed cotton varieties (left to right by increasing trash content): spindle harvested upland, spindle harvested Pima, stripper harvested upland with field cleaning, and stripper harvested upland without field cleaning.

Seed cotton samples of predetermined mass (25, 35, 50, 71 and 100 g) were placed in 652 cc perforated stainless-steel baskets. The baskets weighed approximately 91.5 g; each one was filled with the amount of material specified in the experiment design. In each experimental run we randomized the source material and predetermined mass by position (row within shelf) in the high-capacity drying oven. The same pattern was repeated for runs that had material that was stored or shipped by express air freight, and material that was dried for twice the time recommended (Shepherd, 1972).

Wet weights were taken in the controlled environment, eliminating potential errors from moisture content change while loading and weighing. This was the only step in this experiment that differed from normal research procedures, where wet weights are taken in an uncontrolled laboratory environment.

Seed cotton samples were dried at 104 C (220 F) in the perforated stainless-steel baskets on shelves in the high capacity oven or suspended from the two carousels in the ovens designed for taking dry weights inside. Lint was dried in the same baskets that were used for seed cotton. Cottonseed was dried in small aluminum cups that were placed on shelves in the high-capacity oven, or in perforated aluminum baskets that were suspended from the two carousels in the ovens designed for taking dry weights inside.

Drying took place for the length of time appropriate to each material. Shepherd (1972) specifies a minimum of 1 hour for lint, 5 hours for seed cotton, and 10 hours for seed, or "until the change in weight between successive intervals of at least one hour (15 minutes for lint) is less than 0.1 percent of the specimen weight." Most of the seed cotton samples were dried for 6 hours. The dry weights were taken in two ways: inside one of two drying ovens while the heating elements were still running (Emerson Conditioning Oven, Emerson Apparatus, Gorham, Maine and Mettler Toledo PG1003-S balance, Columbus, Ohio), or on an adjacent electronic balance immediately after removal from a hot high-capacity drying oven (Fisher Scientific Isotemp 750F oven, Hampton, New Hampshire, and Mettler PM1200 balance, Columbus, Ohio). The same electronic balance used to find wet weights was used to find the dry weights. For dry weight determination inside the oven, the balance was placed on a platform above the oven so a hook suspended from the load cell could weigh sample baskets hanging in the oven (Figure 2). For dry weights measured outside of the oven, the sample baskets were placed on the balance above one of the ovens designed for this purpose, or on the balance (in a glass shelter to minimize air currents) on the lab bench next to the high capacity oven (Figure 3).

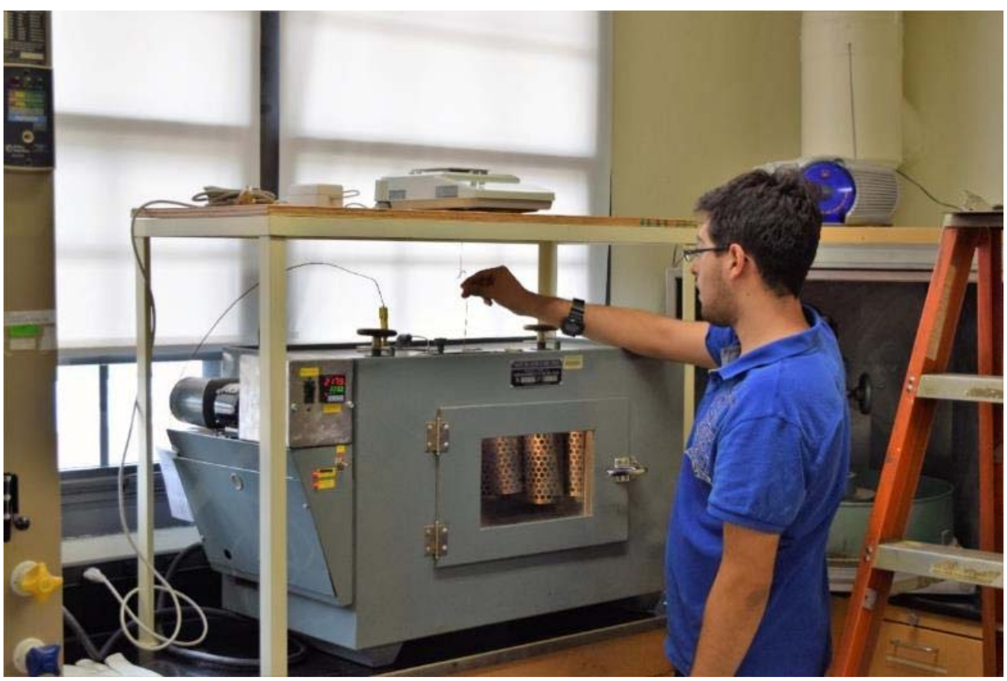

Figure 2. Determining dry weights inside one of the weighing ovens.

Figure 3. Determining dry weights adjacent to one of the high-capacity ovens.

To quantify the buoyancy effect (when measuring dry sample weights outside the oven) apparent moisture content was determined for a material that had no ability to absorb moisture; grade #0000 finest steel wool. With a mean diameter of 0.0254 mm the steel fibers approximate the high end of cotton fiber diameters (which range from 0.011 to 0.022 mm). Baskets were loaded with 25, 35, 50, 71 and 100 g of steel wool, the same weights used with seed cotton. As the amount of steel wool in the fixed-volume basket increased, the volume of air in the space between the steel wool fibers decreased, so the buoyancy effect was expected to decrease with increasing mass.

Results and Discussion

The trash content of the spindle harvested upland was 9.4%, the spindle harvested Pima was 10.7%, the stripper harvested upland with field cleaning was 19.7%, and the stripper harvested upland without field cleaning was 36.8% (Table 2). Apparent moisture content increased with trash content (Figure 4). However, the two spindle harvested cottons, upland and Pima, had a 1.3% difference in trash content but they did not have a measurable difference in apparent moisture content. The stripped upland cotton that was harvested with filed cleaning, the most common method, had an increase in apparent moisture content of only 0.05 percentage points (dry basis) despite the trash content being twice that of spindle harvested upland. Only in the case of unusually high levels of foreign matter, the stripper harvested upland without field cleaning, was the increase in apparent moisture content significant. However, the 0.35 percentage points increase was still a relatively small amount.

Table 2. Seed cotton foreign matter (FM) content determined by fractionation.

	Hulls	Sticks	Motes	Leaf	**Total FM**
Picked Upland	2.6%	0.7%	1.9%	4.1%	**9.4%**
Picked Pima	2.7%	1.1%	2.4%	4.4%	**10.7%**
Stripped, Field Cleaned	7.7%	6.0%	2.4%	3.6%	**19.7%**
Stripped, No Cleaning	13.7%	9.8%	5.2%	8.1%	**36.8%**

Measuring the dry weight of seed cotton outside of the oven compared to inside the oven had the largest influence on apparent moisture content – a difference of about 0.45 percentage points dry basis (Figure 5).

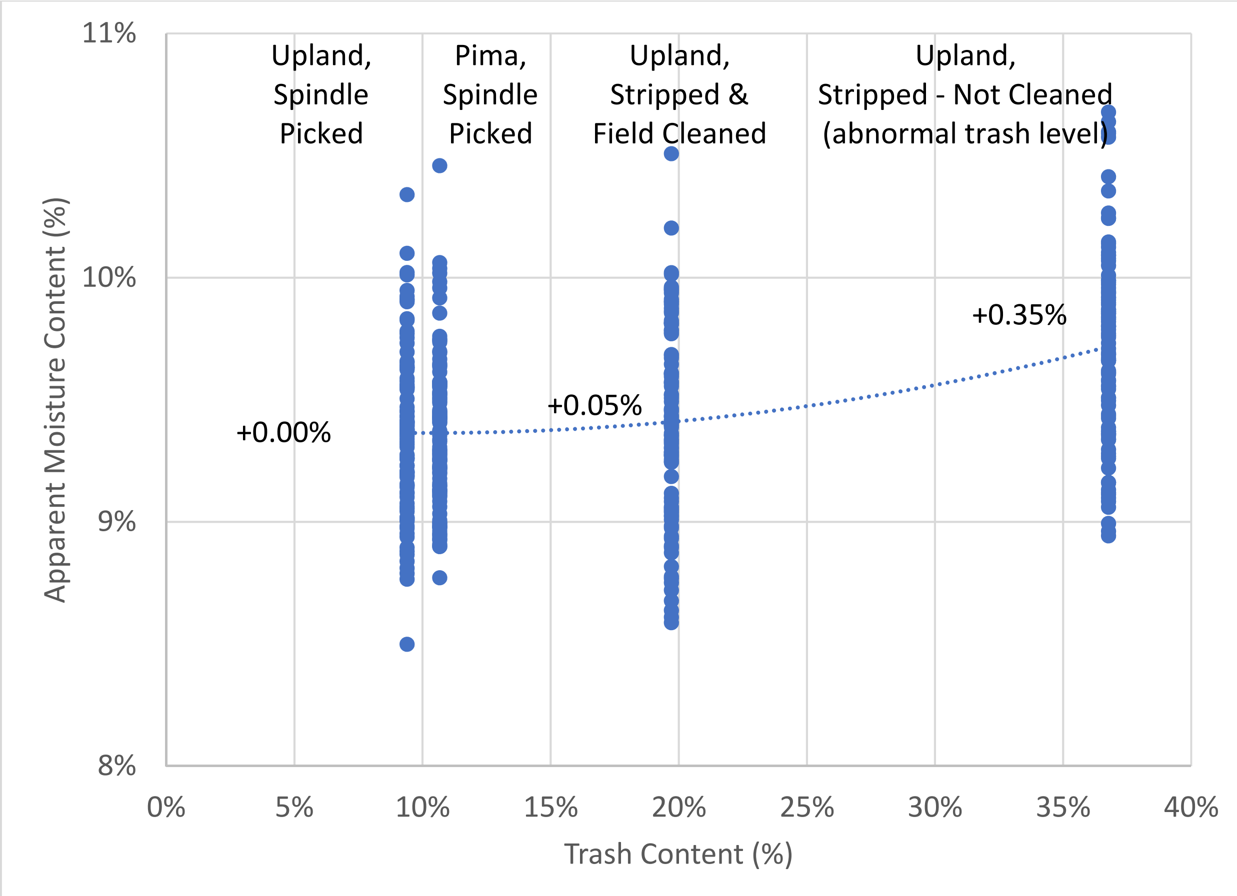

Figure 4. Influence of variety, harvest method, and trash content on apparent moisture content, dry mass basis.

The initial weight of the sample determines the density of the seed cotton in the uniform-sized drying baskets. This determines the volume of air trapped in the seed cotton volume as well. And the air trapped inside the basket with hot, dry seed cotton has a lower density than ambient air, causing the dry sample to weigh less when measured outside of the oven. This decrease in dry weight results in an apparent increase in moisture loss and initial moisture content. Figure 6 shows the apparent moisture content as a function of wet weight, increasing 0.31% when the basket has half the specified seed cotton mass, and decreasing 0.25% if the initial weight is twice the specified 50 g. This artifact of taking the dry weight outside of the oven is known as the buoyancy effect.

The buoyancy effect for a material that has no ability to absorb moisture confirms that the increase in apparent moisture content is caused by the decrease in air density. As the initial weight decreases the denominator in the moisture content calculation, dry weight, decreases. At the same time the numerator, the apparent change in moisture caused by the temperature-induced decrease in the weight of the trapped air, increases because there is more air. The ratio of these two results in a non-linear relationship (Figure 7).

Excess drying time also had an impact on the apparent moisture content. Drying seed cotton for ten hours compared to six increased the apparent moisture content by 0.30% for samples initially weighing 50 g (Figure 8). In addition to the change in apparent moisture content, it was noted that the samples evidenced yellowing following the ten-hour treatment.

The other tested variables: shipping by air freight in 2.7 mil plastic double zipper bags (S-20325, U-Line, Pleasant Prairie, WI); and location in the high-capacity oven were not significant determinations for the apparent moisture content of seed cotton, lint, and cottonseed that was stored in a controlled environment long enough to be at a uniform initial moisture content.

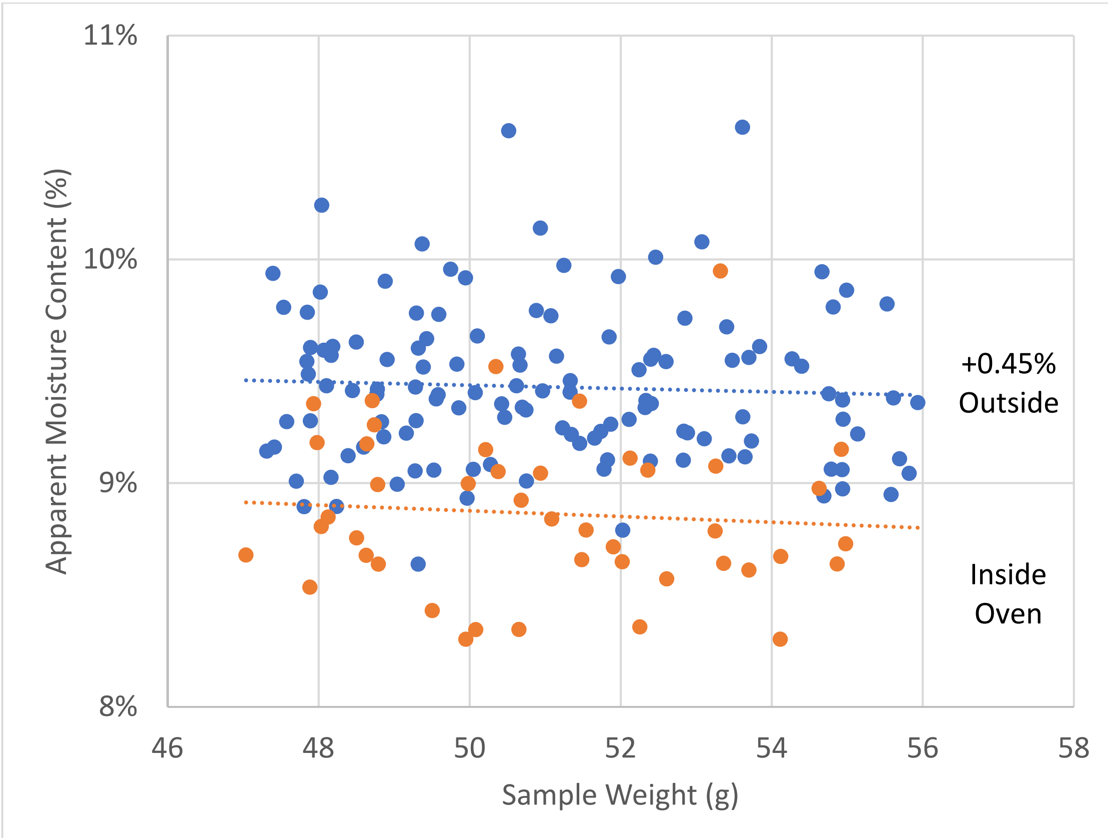

Figure 5. Increase in apparent moisture content when weighed outside of the oven.

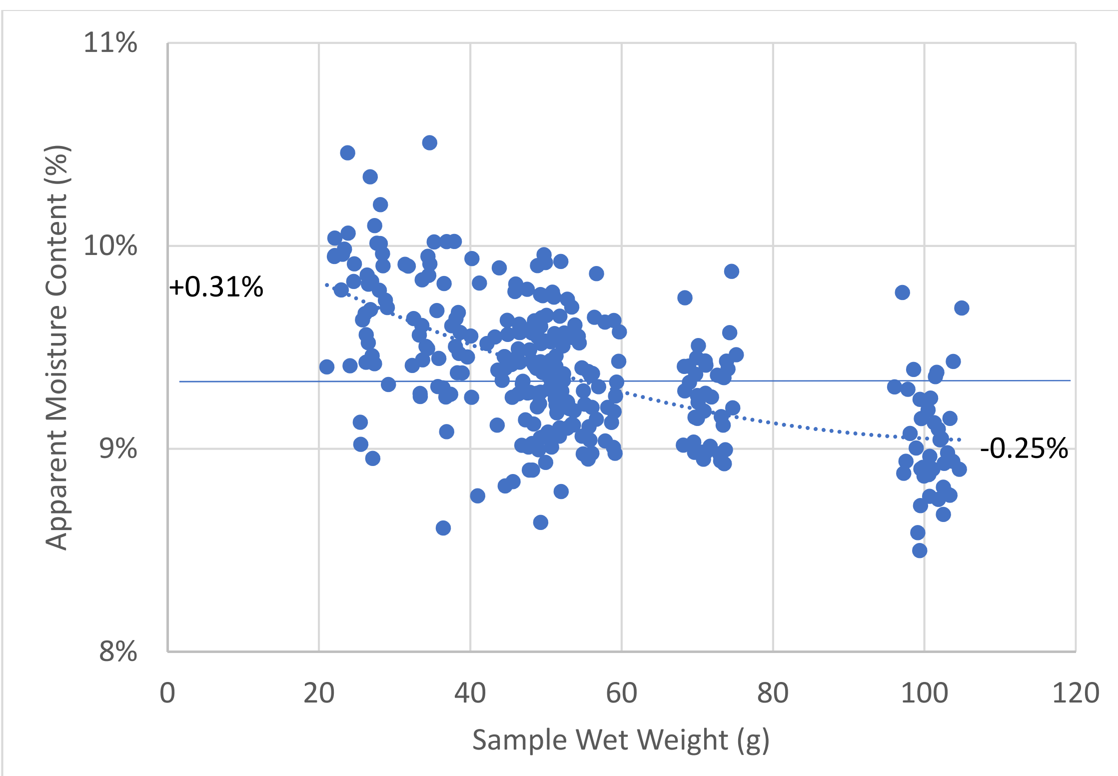

Figure 6. Influence of initial weight on apparent moisture content when weighed outside of the oven.

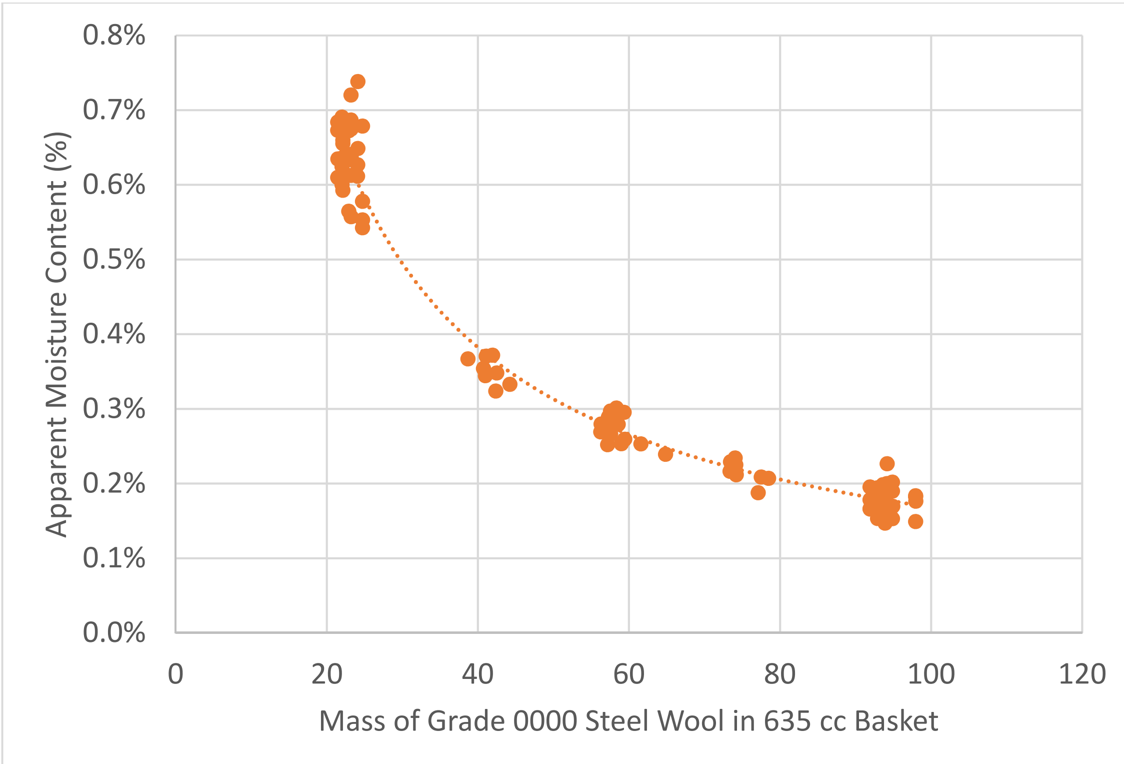

Figure 7. Influence of initial mass on apparent moisture content of steel wool weighed outside the oven.

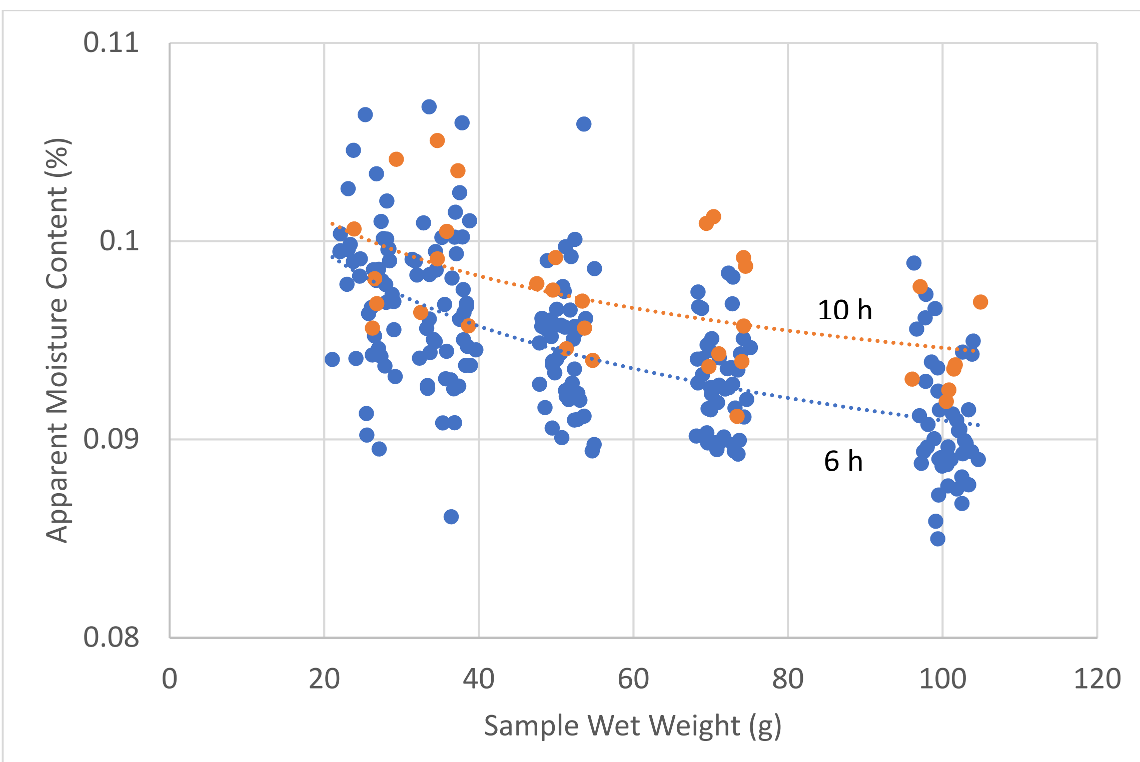

Figure 8. Influence of drying time on apparent moisture content.

Summary

Measuring the dry weight of seed cotton outside of the oven compared to inside the oven had the largest influence on apparent moisture content – the buoyancy effect caused an increase of about 0.45 percentage point dry basis when weighed outside the oven. Because this error is consistent, it does not affect results when determining change in moisture content (for example, before and after a drying process). Due to the buoyancy effect, it is important that the initial mass be close to the value specified by the procedures. Published drying times should also be followed. The amount of foreign matter in seed cotton samples had a minor influence when the trash content was in the range normally encountered. The location of the samples within a high-capacity oven had no impact on apparent moisture content. Shipping and handling, and storage in plastic bags, did not appear to impact moisture content.

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