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Technical Note: Impact of Temperature and Humidity on United States Fine-Wool Fiber Diameter Measurements

Daniel Schaub, Sarah Maninger‡, Brent L. Roeder*‡, Christian J. Posbergh*1*

* *Department of Animal and Range Sciences, Montana State University, Bozeman, MT 59717*

‡ *Montana Wool Lab, Montana State University, Bozeman, MT 59717*

[1] *Corresponding Author: christian.posbergh@montana.edu*

Summary

Fiber diameter is one of the main factors determining wool value with small increases in fiber diameter leading to a loss in revenue. Understanding the factors that lead to inaccuracies in wool fiber diameter testing could help ensure fair pricing of wool for producers in different climates. To determine the effect of humidity and temperature on the diameter of United States fine-wool, 135 wool samples were placed in a temperature and humidity-controlled chamber and acclimated to a range of relative humidity and temperatures. Samples were then evaluated on an Optical Fiber Diameter Analyzer 2000 to measure fiber diameter and other fiber quality metrics. Results show that increases in humidity increase the fiber diameter of wool ($P < 0.05$) but temperature and the interaction between the two had no effect. Producers testing wool fiber diameter in the field with the OFDA2000 may need to consider environmental humidity to increase the testing accuracy.

Key Words: Wool, Humidity, Temperature, Fiber Diameter, Sheep

Introduction

In recent years wool production has been a secondary source of income for US sheep producers compared to other sheep producing countries. In 2021, the United States produced 12,332 tons of greasy wool, making up less than 1 percent of worldwide wool production (IWTO, 2021). Comparatively, countries like Australia and China have large shares of the global wool market, producing 18.3% and 17.1% of global wool production respectively (IWTO, 2021). Demand for wool has decreased in the United States due to increased competition with less expensive synthetic fibers (Ashton et al., 2000). Furthermore, traditional markets for wool, such as outer knitwear and woven suit attire, have shrunk due to increased casualization of the workforce, limited trans-seasonal clothing options, and increased discretionary spending during unfavorable economic conditions (Doyle et al., 2021).

Wool marketing has shifted toward new markets such as next-to-skin clothing (Rowe, 2010). Next-to-skin clothing requires wool to have a high comfort value, which is largely based upon the prickling factor of the fiber. The prickling factor of wool-based clothes is associated with increased buckling fibers that protrude from the fabric (Naebe et al., 2015). A fiber's buckling response (*F*) is determined by the equation

$$F = \frac{\pi^3 * Ed^\wedge 4}{31.36L^2},$$

where *E* is Young's modulus, *d* is the fiber diameter, and *L* is the length of the protruding fiber (Naebe et al., 2015). As fiber diameter increases, so does the buckling response, which then decreases the comfort level as more protruding fibers rub and irritate the wearer's skin. Thus, the importance of lower diameter fiber wool production has increased as the next-to-skin wool clothing markets expand. As lower fiber diameter wool is usable in a more extensive range of textiles, due to the higher comfort factor, it is priced higher on a weight basis, making wool prices inversely associated with fiber diameter (Cottle and Baxter, 2015). Therefore, to increase profits from wool, producers have a further incentive to breed animals that grow finer diameter wool.

To accurately determine the fiber diameter of wool, fiber analysis machines are used. Three common machines used to analyze wool for its diameter are the Fiber Lux Micron Meter, the Optical-based Fiber Diameter Analyzer 2000 (OFDA 2000) and the Sirolan-Laserscan™, The Sirolan-Laserscan™ machine works through laser-based fiber diameter analysis. First. the machine project lasers through the wool fibers within a measurement cell. The resulting beam is then split between two points a detector and a fiber optic discriminator which measures the beam and allows the processer to determine the width of the sampled wool (Botha and Hunter, 2010). The Fiber Lux uses light diffraction to determine fiber diameter (Walker et al., 2018). The OFDA 2000 works through optical diameter measurements. This machine is operated by first putting samples in a wire-framed slide where the frame is traversed by a low-powered microscope while being illuminated stroboscopically from below. The wool sample is traversed by the microscope at each increment of the staple and measures the fiber diameter at regular intervals (Baxter, 2001). These diameters are then averaged through the entire wool grab. The OFDA 2000 has been used to accurately sort lines of wool in-field in real-time for large producers (Kott et al., 2010). Accuracy in using these machines in the wool testing process is vital to fairly price wool and select sheep with lower fiber diameter wool. Differences in wool sample diameter between New Zealand and Montana State testing labs have been discovered that indicate there may be outside factors that are impacting the fiber diameter of samples.

As sheep producing regions differ in climates, changes in temperature and humidity may be affecting in-field fiber diameter measurements. Wool is water absorbent with an absorbance level of around 11% water weight per wool dry weight (Van Amber et al., 2015). Water molecules act in a diffusion-like manner with keratin structures in wool. Keratin chains "diffuse" into the space left vacant by the water molecules when water molecules evaporate and vice versa. The water molecules interact with the keratin proteins which replace the protein-protein interactions and form a keratin-water network instead (Feughelman and Robinson, 1967; Wortmann and De Jong, 1985). Wool appears to have a two-phase model for water absorption, where the first 10-15% of water absorbed is stored as monolayer at strongly reactive absorption sites along the fiber and when relative humidity is greater than 14% absorption occurs at weakly reactive sites (Wortmann and De Jong, 1985). However, this absorption rate is also controlled by the Hofmeister effect where differences in hydrophobic ions alter the presence of water in the wool fibers (Lo Nostro et al., 2002). In cases where these ions are present this could increase the water density in wool fibers making them test at a higher fiber diameter value. If the water from increased relative humidity is absorbed into wool and subsequently increases wool fiber diameter, fiber diameter analysis will be biased towards larger values.

Temperature and humidities within and between fine wool producing regions can vary widely depending on location and time of day. Great Falls, Montana has an annual average relative humidity of 45% and annual average temperature of 5.3 °C compared to Houston, Texas that has an annual average relative humidity of 59% and annual average temperature of 19.2 °C (NCEI, 2018; NCEI, 2023). There is variation present within each region as well with Kalispell, Montana having an annual average relative humidity of 54%, 9% higher than Billings, Montana (NCEI, 2018). Therefore, there may be inaccuracies in testing for fiber diameter even when comparing flocks within regions if it is affected by the humidity conditions in which it is stored. Humidity and temperature also changes based upon the time of day. Between morning and afternoon, the average humidity for Billings, Montana differs from 66% to 48% (NCEI, 2018). Therefore, fiber diameter tested by an OFDA in the field may be biased if these variables change through the day or wool brought to a pool for testing has been stored in different conditions. Understanding if and how the environmental differences of temperature and humidity is impacting fine wool analysis when testing in the field is crucial to ensuring the accuracy of wool fiber diameter testing.

One of the issues the Montana Wool Lab faces when helping small and medium sized growers is the inability to be at every farm and ranch during shearing with wool handling equipment and many shearing crews cannot economically pay a classer for small flocks. Due to this, the OFDA2000 is used at wool pool deliveries to test samples of baled or packaged wool as it is delivered to determine the appropriate market line. There is no published research on testing packaged wool in-field that has been stored under different environmental conditions and may vary in moisture content while testing. The objective of this study was to evaluate how different relative humidity and temperatures may influence wool fiber diameter measurements when using the OFDA 2000 for possible adjustments when in-field testing of United States fine wool.

Materials and Methods

One hundred thirty-five 7.5 to 12.5 cm staple length wool clips were collected over five different shearing dates. Wool samples were shipped to the Montana Wool Lab where all fiber measurements were taken. Wool samples were washed through a sonicating bath of hexanes for 10 minutes and allowed to dry for 30 minutes. A controlled humidity and temperature chamber (The-SausageMaker, Model# 19100, Buffalo, NY) was used to subject the wool samples to the temperature: relative humidity combinations listed in table 1. Each individual sample was subjected to every temperature: relative humidity combination (Table 1). Samples were acclimated to each temperature and relative humidity level for at least 12 hours prior to measurement. Samples were removed and analyzed in ten sample batches to avoid loss of acclimation before measurement. The samples were measured for fiber micron diameter with the OFDA 2000.

Using R, a repeated measurements ANOVA was performed to evaluate the effects of the independent variables (Temperature and Relative Humidity) on the dependent variable of mean fiber diameter. An interaction between Temperature and Relative Humidity was included in the model.

Table 1: Temperature and Relative Humidity Percentage treatment combinations applied to each individual wool sample.

Treatment Combination	Temperature (°C)	RH[1]
1	4.4	35
2	10.0	35
3	15.5	35
4	4.4	40
5	10.0	40
6	15.5	40
7	4.4	45
8	10.0	45
9	15.5	45
10	4.4	50
11	10.0	50
12	15.5	50
13	4.4	55
14	10.0	55
15	15.5	55
16	4.4	60
17	10.0	60
18	15.5	60
19	4.4	65
20	10.0	65
21	15.5	65

[1] Relative Humidity Percentage

Results and Discussion:

Average sample fiber diameter ranged from 15.4 to 24.47 microns across all treatment combinations. Average fiber diameter for each temperature and relative humidity combination can be found in Table 2. No significant interaction effect of temperature and relative humidity was detected ($P > 0.05$). Wool fiber diameter was found not to be associated with temperature ($P > 0.05$) but associated with relative humidity ($P < 0.05$). As humidity increases, so does the mean wool fiber diameter, as shown in Figure 1. However, the effect size of humidity is small, with an increase of approximately 0.005 microns in diameter for every one RH percent increase within the range tested (Figure 1).

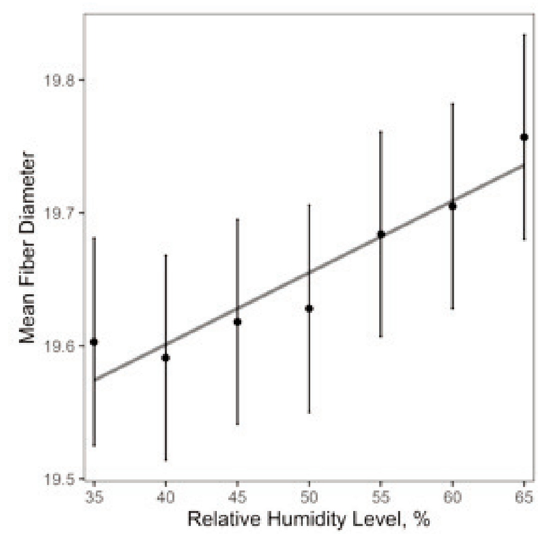
Our results suggest that relative humidity levels impact the fiber diameter measured in samples with more humid treated wool staples having higher micron values. These results are consistent with Naebe (2013) which indicates that the wool Comfort-Meter™ values, which are inversely related to fiber diameter, were reduced at

Table 2: Average fiber diameter (± standard deviation), in mi of 135 wool samples by relative humidity and temperature treatment.

	Temperature °C		
RH[1]	4.4	10	15.5
35	19.62 ±1.58	19.57 ±1.56	19.62 ±1.57
40	19.54 ±1.55	19.58 ±1.56	19.65 ±1.54
45	19.58 ±1.56	19.62 ±1.55	19.65 ±1.54
50	19.59 ±1.54	19.65 ±1.59	19.64 ±1.57
55	19.65 ±1.55	19.66 ±1.54	19.73 ±1.56
60	19.67 ±1.55	19.67 ±1.53	19.79 ±1.56
65	19.75 ±1.56	19.77 ±1.55	19.76 ±1.55

[1] Relative humidity Percentage

Figure 1: Mean Fiber Diameter (with standard error bars) plotted against Relative Humidity Level.



greater levels of humidity (Naebe et al., 2013). The effect of humidity on wool fiber diameter appears to begin at around 50% relative humidity. Climate data indicates that relative humidities in areas with fine wool production often exceeds 50% humidity in parts of or throughout the whole day (NCEI, 2018). Therefore, the expanding effect relative humidity has on wool is relevant to in-field testing of wool produced and stored in these regions.

The impacts of humidity on fiber diameter may therefore be essential to control in order to increase in the field wool testing accuracy. In the field, wool testing may vary depending upon the humidity which is largely driven by time of day. Time of day variations of humidity levels can be as great as 30% between morning and night in places such as Bloomington, Texas (NCEI, 2018). Wool exposed to these higher humidity levels in the morning may have increased fiber diameter than if it were shorn and analyzed in the evening when it may be less humid. As many shearing operations start in the morning and shear all day there may be a difference in fiber diameter found between morning and afternoon shearing. Furthermore, wool fiber diameter may be artificially increased in regions of the United States with higher humidity such as the Northeast and Southeast as opposed to the Southwest and Intermountain West. Differences in humidity levels between regions can be great as 30% on average (NCEI, 2018). Therefore, field testing in regions with higher humidity may assign wool samples higher fiber diameters than testing in less humid climates.

In the field testing of individual samples could lead to sheep being undervalued for their wool performance in high humidity areas and some sheep being overvalued in low humidity areas. From this misvaluing of breeding stock, selection towards smaller fiber diameter wool in flocks could be altered and progress potentially slowed if samples from different flocks are being tested at different in-field environmental conditions that are not accounted for. Differences in storage practices and processing of wool bales may result in differences in humidity within the bale, thereby affecting the in-field measurement of samples, and potentially changing the marketing line that wool is assigned to. Furthermore, while this study did not increase RH past 65% some wool producing areas may have relative humidities as great as 90% on any given day (NCEI, 2018). Using the results from this study, wool fiber diameter measurements on a 90% RH day would be 0.2 microns thicker than a 50% RH day. This line shift could cause an approximately $0.20/pound grease weight reduction that producers receive for their wool, based on historical averages for the Eastern Consolidated Wool Pool (unpublished data).

While this study shows that fiber diameter is increased in higher relative humidity, further work is needed to determine if other factors in field may play a part in altering fiber diameter measurements. The study design does allow for interpretation of the effect humidity and temperature has on fiber diameter in a controlled setting. However, large in field data may be needed for more accurate information to what the actual effects of humidity and temperature are in field. Furthermore, interactions between the original fiber diameter and relative humidity might be limiting the effect relative humidity we found. Further studies may select for similar micron size in samples before application of treatments to control for beginning fiber diameter and relative humidity interactive effects better.

The overall differences in fiber diameter measured in environments with different humidity supports an equalizing process where wool samples are treated to the same humidity before analyzing for fiber diameter, which occurs in wool labs but is not practical when in field testing. However, as the effect size of humidity on fiber diameter is small, there may not be an economic incentive to push for such practices. Further study on the economics of this fiber diameter difference is needed to determine whether such a practice is economically beneficial.

Conclusion:

Here we show that humidity increases the diameter of wool fibers while temperature does not. The economic impact of the inaccuracy of testing due to humidity, however, is likely minimal but may be important for wools tested near cut-offs for specific lines when collecting at wool pools and downstream usages. Further research into other factors affecting fiber diameter may be needed to fully understand differences observed between fiber analysis equipment used in the field.

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