Relationship Between Cotton Varieties and Moisture Vapor Transport of Knitted Fabrics

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ABSTRACT

Cotton offers *next-to-skin* comfort and hence is a preferred fiber for undergarments. There have been a number of studies on the effect of different fiber types, fabric structure, fabric finishes, etc. on the moisture vapor transport properties. However, there has been no report in the public domain on the relationship between cotton varieties on the moisture vapor transport characteristics of fabrics produced from them. The study reported in this paper focuses on the moisture vapor transport properties (MVTR) of cotton fabrics knitted from 31 different cotton fibers with different pedigrees grown over a three-year period in three major cotton growing regions of US, Southwest (Texas), Mid-South (Mississippi) and Southeast (Georgia). Results indicate that cotton varieties influence the MVTR of knitted fabrics produced from them. This study, for the first time has attempted to link varietal effects on the most important property of cotton—breathability quantified using MVTR. Preliminary analysis indicates a relationship between the basic sugar content such as verbascose of cotton and its moisture vapor transport. However this result has to be followed up with a thorough study.

INTRODUCTION

One of the inherent characteristics that makes cotton “king” among fibers and enhances consumers’ appeal is its comfort characteristics. Comfort here does not refer to the psychological comfort but to the physiological comfort such as the moisture vapor transport rate (MVTR). The rate at which water vapor moves through a fabric plays an important role in determining the comfort as it influences the human perception and the cool/warmth feeling. Human body produces moisture in the form of perspiration, which should leave the microclimate between the skin and fabric before condensation to avoid clinging of fabric on to the skin, keeping the fabric and skin surface dry[1, 2]. When a fabric allows the transport of water vapor at a faster rate, it is said to be a breathable fabric. In other words, the faster a fabric breaths, the better is its comfort. This property has direct implications on the end-use applications, consumer appeal and sales value of the fabric. More importantly, in the case of cotton, its inherent characteristic is its comfort on which it is pre-sold to customers[3]. By controlling the moisture vapor transport properties of 100% cotton, it was possible to develop a wide range of performance apparel fabrics for athletic activities.[4]

There have been a number of reports on the moisture vapor transport characteristics of fabrics. Guo’s work concluded that the amount of softener used, the different varieties of fabrics and their interactions influence the water vapor transport.[2] Guo’s research focused on both 100% cotton and 100% polyester light weight plain woven fabrics, treated with and without laundry softener during both rinsing and drying cycles. It is obvious from this study that the main focus was to understand the effect of fabric softener on fabric properties such as MVTR. Gretton, et al., investigated the moisture vapor transport through multilayered fabrics which simulates the actual clothing system using the evaporative dish method, British Standard (BS): 7209, and reported that the moisture transmission property of the clothing system lowers with the addition of layers of fabrics such as 1x1 rib knitted cotton T-shirt fabric, double sided weft insert polyester fleece fabric and 2/1 twill polyester lining fabric underneath the outer breathable fabric. They also found that it is possible to predict the MVTR of multilayered fabric based on the MVTR values of single layer using the empirical relationship as given in Equation 1[5].

$$\text{Multiple layer \% MVTR} = \text{Outer Fabric \% MVTR} \times \frac{\text{Lining\% MVTR}}{100} \times \frac{\text{Fleece \% MVTR}}{100} \times \frac{\text{T} - \text{shirt \% MVTR}}{100} \qquad (1)$$

A few studies have discussed the influence of air spaces in textile structures on their moisture vapor transport and have proposed an alternative hypothesis on the influence of voids on the transport properties in fabrics. Water vapor permeability is largely affected by the air spaces surrounding the fibers in both yarns and fabrics[6]. These air spaces offer resistance to the flow of moisture through the textile structures. Goodings, et al., found that in the case of textile materials, which are a conglomeration of fibers and air, the resistance offered by air pockets for moisture diffusion is greater than the resistance offered by the testing materials itself and so any method devised to quantitatively measure the MVTR of textile materials needs both precise and efficient ways to remove the air spaces. This result is controversial and has not been verified by other researchers. For this work they used low-resistance laminae made of perforated metal plates and 57 different woven fabrics and felts made from fibers like cotton, wool, silk, acetate, viscose, nylon, glass, orlon, saran and polyethylene. Their work concluded that the relationship between the diffusion resistance and thickness of the fabric is linear but not proportional.

Fourt and Harris[7] used polyacrylic resins for embedding fibers like cotton in the form of sliver, rayon, wool, nylon and polyester in the form of tops, to eliminate the air spaces problem. They measured the MVTR as a diffusion constant for the above mentioned fibers and found cotton to be the best with highest diffusion constant ($134 \times 10^{-4} \text{cm}^2/\text{sec}$). Presence of central lumen in cotton fibers is believed to influence the moisture vapor transmission, but this was not completely evaluated and proved. In their other work[8], they used woven fabrics made from fibers like glass, vinyon, cotton, viscose, rayon, wool, nylon and cellulose acetate and found that the resistance of fabrics to the passage of water vapor depends on factors like, fiber type, fabric thickness and its tightness.

Most recently, there has been renewed interest in understanding the moisture properties of cotton and its relationship with fiber properties. This has been primarily due to the need to develop new cotton varieties that have unique properties related to comfort and end-use applications such as outdoor performance clothing. To have excellent comfort, it is not how much water that is absorbed by cotton, rather how much moisture vapor the fiber is able to transport that is most important.

Recent studies[14-16] on the effect of varieties and area of growth on moisture absorption property of cotton fiber which is different from the transport of vapor indicates that cotton grown in Texas was least mature and thus had the highest water of imbibition (WOI) values. As is reflected in the way that WOI is measured; it does not reflect the transportation of vapor through fibers. WOI measures water that is within cell walls, in inter-fiber spaces and in pores. Cotton from Mississippi had the lowest WOI value and cotton from Georgia fell in between those of Texas and Mississippi. High WOI was related to the loose and more open arrangement of microfibrils in the primary wall compared to secondary wall, which enables immature cotton to imbibe more water. Rousselle and French[15] have reported the moisture absorption in cotton varieties grown in Mississippi and Georgia in the crop year 2003 and its relationship to maturity or micronaire of the cottons. Their results show that micronaire and moisture regain of cotton fiber have inverse relationship on the moisture absorption properties as quantified by WOI. Gamble[16] in his work tested 21 different cotton varieties planted in three different locations and established a relationship between fiber maturity and moisture content which indicates that there is an inverse non-linear relationship between micronaire and fiber moisture content. This concurs with the results obtained by Rousslle and French[14, 15]. However, to the authors' best knowledge, the relationship between different cotton varieties and their moisture vapor transport characteristics, which is a measure of comfort, has hitherto not been reported.

A number of test methods are available to quantify the moisture vapor transport through fabrics. The work reported in this paper uses the British Standard evaporative dish method BS: 7209:1990[9] and has been found to be logical due to the following reasons: a) Gretton, et al., reported that different methods available are not comparable as differences exist in the vapor pressure gradients in each method and so they concluded that evaporative dish method is simple and easy to rank and compare fabrics[10]; b) Hu, et al., found that water vapor permeability results based on wet cup method described by the ASTM E 96-95 standard did not give accurate and reliable results and so a modified method was used to determine the water vapor transport properties, which is very similar to evaporative dish method[11] and c) Gibson's study on various techniques available for measuring MVTR properties of fabrics suggest that the intrinsic property of material under test is altered by many methods and so their results do not agree with each other.[12] From the studies reported above, evaporative dish method is a reliable method to quantify MVTR of fabrics.

Based on the aforementioned brief discussion, earlier studies have focused predominantly on understanding the effects of fiber types, fabric structure and different testing conditions and methods to quantify MVTR of textile materials[13]. However, there is no report on the relationship between different cotton varieties and the moisture vapor transport through knitted fabrics made from them. This paper has attempted to investigate the effect of fiber pedigree/cotton varieties on the breathability of knits made from them. More importantly, an attempt has been made to understand the effect of the basic sugar molecules in cotton fiber on the breathability values, which is a new direction of research hitherto not undertaken. This study will help with the breeding of cotton for superior characteristics for targeted end-use applications. Having a better understanding on the relationship between the fundamental build up of cotton and MVTR of fabrics made from them is of extreme value to the entire segment of fiber-fabric industry as cotton is pre-sold to consumers based on its comfort value. However, a robust and thorough study on this subject is needed, which will be the subject matter of forthcoming studies.

EXPERIMENTAL

Materials

As the main objective of this study was to understand the influence of cotton varieties on the moisture vapor transport rate of knitted fabrics made from them, it was thought logical to evaluate the MVTR in griege fabric form without any further treatments. Any further treatment to the knitted fabrics was thought to interfere with the study on the understanding of varietal influence on MVTR values. The effect of finishes and further treatments on greige fabrics on their MVTR is a separate study in itself and is outside the purview of this paper. This paper in no way denies the influence of fiber type, yarn, fabric structure, construction and finishes on the MVTR. These factors have been well researched and documented[2,5]. This paper is built on the hypothesis that beyond these aforementioned variables, cotton fiber chemistry and varietal differences do influence the MVTR of fabrics. Thirty one single jersey fabrics were knitted from yarns from different cottons which include the most popular US cotton varieties grown in Mississippi, Georgia and Texas during the crop years 2001, 2002 and 2003. The selection of varieties over the three year period was thought to be a good representation to understand the relationship between varietal differences and their influence on the moisture vapor transport of fabrics made from them. The average loop length of the fabrics was 0.36 cm and the average tightness factor was 15.09. Table I gives the properties of different cotton varieties and their breeding origins. Varieties derive from six different breeding programs and a range of breeding methods including: forward crossing where conventional or transgenic varieties are selected from a cross of diverse parents, transgenic backcrossing where transgenes are transferred to elite varieties using recurrent backcrossing and selection of novel varieties out of existing varieties. Figure 1 shows the processing stages in converting cotton to knitted fabrics. The processing of cotton to knitted fabrics was carried out in the Cotton Quality Research Unit, ARS Laboratory, USDA, Clemson, SC, USA.

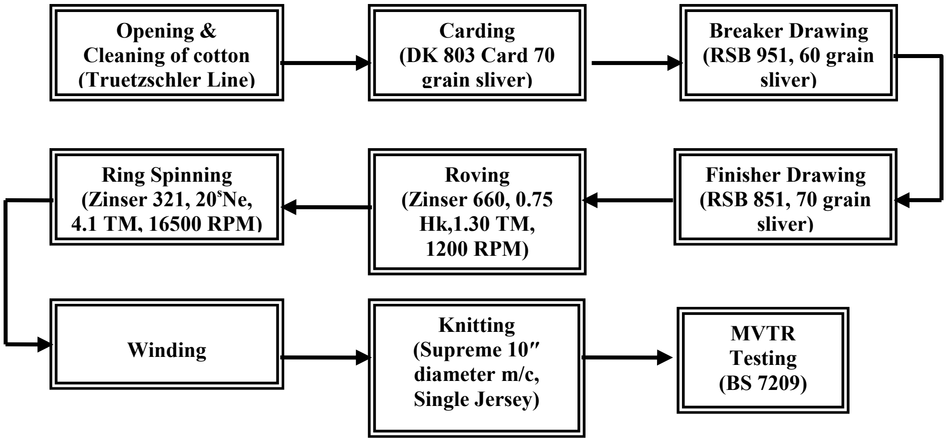

Figure 1. Flow Chart of Cotton Processing to Knitted Fabrics

Table I. Properties of Cotton Varieties

Code	HVI Micronaire (µg/inch)	HVI Strength (g/tex)	HVI Length (inch)	AFIS Maturity Ratio	Breeding Origin	Breeding Method
A	4.48(0.17)	28.10(1.21)	1.080(0.03)	0.895(0.02)	Queensland ,Australia	Transgenic Backcross
B	3.53(-)	27.07(-)	1.080(-)	0.780(-)	Mississippi, US	Transgenic Backcross
C	3.64(0.37)	27.93(0.25)	1.090(0.01)	0.835(0.01)	Texas, US	Transgenic Backcross
D	4.30(0.23)	30.13(0.95)	1.154(0.03)	0.906(0.03)	Mississippi, US	Forward Cross
E	4.53(0.16)	28.94(0.88)	1.123(0.03)	0.912(0.02)	Queensland, Australia	Forward Cross
F	4.08(0.43)	28.39(0.86)	1.070(0.01)	0.850(0.01)	Texas, US	Transgenic Backcross
G	5.56(-)	26.26(-)	1.050(-)	0.940(-)	Louisiana, US	Transgenic Backcross
H	4.03(-)	27.60(-)	1.120(-)	0.880(-)	Arkansas, US	Transgenic Forward Cross
I	4.98(0.3)	25.68(1.9)	1.085(0.03)	0.848(0.01)	Mississippi, US	Selection out of Commercial Variety
J	4.17(0.75)	29.64(1.52)	1.112(0.05)	0.882(0.03)	New South Wales, Australia	Forward Cross

The parameters in parenthesis are standard deviations of means of different Variety/Location/Year samples. Few varieties had only one Location/Year sample and hence their standard deviations are not reported.

Moisture Vapor Transport Evaluation

Evaporative dish method based on the British Standard, BS 7209 was used to determine the moisture water vapor permeability (MVTR) of fabrics. As per the British standard[9] the test specimen is sealed over the open mouth of a test dish which contains water and the assembly is placed in a controlled atmosphere of 20°C and 65% relative humidity. Following a period of one hour to establish equilibrium of water vapor pressure gradient across the sample, successive weighing of the assembled dish were made and the rate of water vapor permeation through the specimen is determined.

Prior to testing, the samples were conditioned for 24 hour at standard atmospheric conditions (20±2°C and 65±5% RH). For each fabric, five test specimens were cut having diameter slightly more than the dish rings. The inner diameter of the ring was 8.2 cms. By means of a burette, 46 ml of distilled water was transferred to the open dish. A triangular support placed on the open dish was used to maintain 10±1 mm deep layer of air between the surface of the water and the underside of the specimen. Then the specimen was placed above the rim of the dish with a quick drying, thin and continuous layer of adhesive. The test fabric was placed in such a way that the surface which was intended to be on the outside of the clothing assembly faced upwards or on the top. Finally, the cover ring is positioned above the rim and pressed down firmly with a strip of adhesive tape around the full circumference, sealing the joint between the cover ring and the dish.

The fabric on the evaporative dish and the MVTR turntable equipment are shown in Figures 2 and 3. Evaporative dishes with fabrics were mounted on the turntable and were allowed to rotate for one hour to establish equilibrium. At the end of the equilibration period, each assembly was weighed to the nearest 0.001grams. Then the turntable was allowed to rotate for five more hours in the controlled atmosphere and the assemblies were reweighed at the end. The MVTR in g/m^2/day is calculated as given in Equation 2:

$$\mathrm{MVTR} = \frac{24\mathrm{M}}{\mathrm{At}} \tag{2}$$

where,

M is the loss in mass of the assembly over the time period t in grams;
t is the time between successive weighing of the assembly in hours and
A is the area of the exposed test fabric (0.005413 m^2).

Figure 2. Evaporative Dish Assembly

Figure 3. MVTR Turntable

RESULTS AND DISCUSSIONS

The MVTR values for 31 samples were calculated using the formula given in Equation 2 and are given in Table II and Figures 5. As is evident from the results, Variety A was found to have the highest MVTR rates and hence would give better comfort to the wearer compared to other varieties based on MVTR values. The MVTR values were statistically analyzed using analysis of variance (ANOVA) in JMP Version 5.0 (SAS Institute, Cary, NC, USA). Since the trials were unbalanced with regards to variety, Least Square Means (LS Means) were used for both variety and location MVTR comparisons. Differences between variety and location MVTR LS Means were statistically significant at the <0.0001 level (Variety F=6.69 for df=9; Location F=20.68 for df=2). No significant interaction effects between variety and location was observed. When significance was obtained, Tukey-Kramer honestly significant difference (HSD) was preformed to compare significant differences between groups ($P < 0.05$). LS Means for variety and location effects on MVTR are given in Tables III and IV. LS Means matched by one or more similar letters as shown in Table VI are not significantly different at the P=0.05 level. Therefore, from results it is evident that MVTR of Variety A significantly differs from those of Varieties I and J. Similarly looking at the location, MVTR of cotton from Mississippi is significantly different from that of Georgia.

Surprisingly, basic fiber properties such as micronaire, length, maturity ratio and short fiber content are poorly correlated with MVTR. However, micronaire is negatively correlated with MVTR.

Table II. MVTR Readings of Different Cotton Knitted Fabrics

Variety	**Avg MVTR ($gm/m^2/day$)**	**SD ($gm/m^2/day$)**	**CV %**
EG01	1174.43	53.07	4.52
DG01	1261.36	18.18	1.44
IG01	1218.78	14.84	1.22
EM01	1388.21	103.25	7.44
DM01	1379.34	27.34	1.98
IM01	1357.16	69.85	5.15
GM01	1289.15	42.97	3.33
CT01	1286.20	25.86	2.01
J T01	1222.33	46.69	3.82
FT01	1328.77	26.91	2.03
EG02	1327.00	37.95	2.86
DG02	1330.55	58.03	4.36
J G02	879.94	35.70	4.06
IG02	892.35	36.89	4.13
AG02	1316.36	21.36	1.62
EM02	1177.98	45.83	3.89
DM02	1263.13	11.90	0.94
JM02	1364.26	49.94	3.66
IM02	1344.74	47.19	3.51
AM02	1385.55	47.52	3.43
CT02	1383.77	45.66	3.30
FT02	1188.62	40.16	3.38
BT02	1357.16	47.35	3.49
JT02	1140.72	18.39	1.61
EG03	1292.11	30.56	2.37
JG03	1264.91	39.97	3.16
AG03	1378.45	35.26	2.56
DM03	1371.35	40.45	2.95
EM03	1408.61	29.02	2.06
HM03	1302.46	85.71	6.58
*AM03	1441.42	82.71	5.74

*Based on average of 10 repeats. All other fabrics were repeated 5 times. A-J Fiber variety, G-Georgia, T-Texas, M-Mississippi and last two digits refers to the crop year

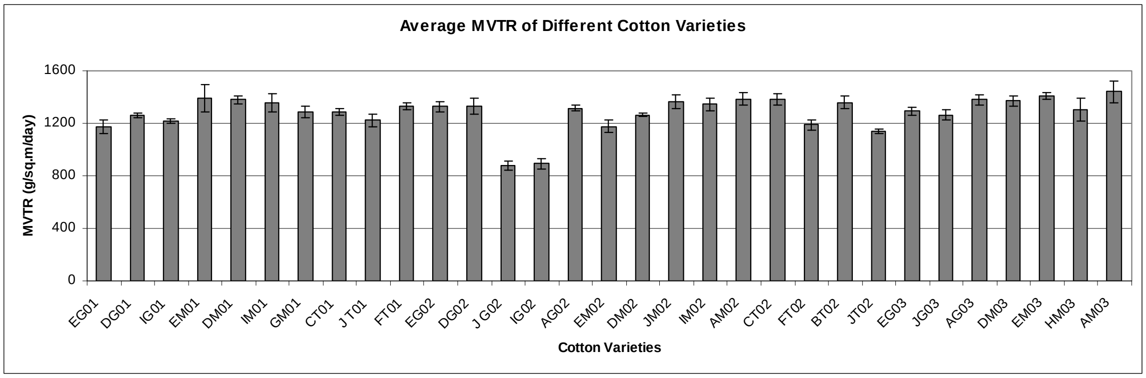

Figure 4. MVTR of Knitted Fabrics from Different Cotton Varieties

Table III. Least Squares Means of Varieties

Level	Least Sq Mean	Std Error	Mean
Variety A	1376.33	25.91	1392.60
Variety B	1363.83	55.71	1357.20
Variety C	1341.73	44.42	1335.10
Variety D	1307.53	25.91	1323.80
Variety E	1294.72	24.24	1298.03
Variety F	1265.23	44.42	1258.60
Variety G	1236.13	50.95	1304.20
Variety H	1253.73	50.95	1321.80
Variety I	1199.83	27.85	1203.15
Variety J	1188.13	21.58	1174.52

Table IV. Least Squares Means of Location

Level	Least Sq Mean	Std Error	Mean
Georgia	1221.28	21.35	1213.82
Mississippi	1350.79	20.30	1354.74
Texas	1276.09	30.88	1272.51

Table V. ANOVA Table for Difference Between Means Of Varieties And Locations

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Variety	9	9	681089.56	6.69	<.0001
State	2	2	467648.72	20.68	<.0001

Table VI. Variety wise MVTR Least Square Mean Differences and Tukey-Kramer HSD

Level	Least Sq Mean	
Variety A	1376.33	A
Variety B	1363.83	ABC
Variety C	1341.73	AB
Variety D	1307.53	A
Variety E	1294.72	ABC
Variety F	1265.23	ABC
Variety H	1253.73	ABC
Variety G	1236.13	ABC
Variety I	1199.83	BC
Variety J	1188.13	C

Levels not matched by same letter are significantly different

Table VII. Location wise MVTR Least Square Mean Differences and Tukey-Kramer HSD

Level	Least Sq Mean	
Mississippi	1350.79	A
Texas	1276.09	AB
Georgia	1221.28	B

Levels not connected by same letter are significantly different

Table VIII. Correlation between MVTR and Fiber Properties

Fiber Properties	Correlation Coefficient (r)
Micronaire	-0.227
Strength	0.216
Length	0.241
Short Fiber Content	0.111
Maturity Ratio	0.116
Neps	-0.003

Length, short fiber content and maturity ratio are positively correlated as shown in Table VIII. The results from the relationship between MVTR and basic fiber characteristics indicate that fiber properties may not have significant influence. It seems that vapor transmission through the cell is influenced at the molecular level during fiber development. To have a better understanding, there needs to be further studies done on fiber development and comfort related characteristics such as MVTR.

RELATIONSHIP BETWEEN FIBER CHEMISTRY AND MVTR

As is evident from the results, there seems to be an effect of fiber varieties on MVTR with Variety A giving the best MVTR values. Based on this finding, a newline of preliminary investigation hitherto not undertaken was carried out to understand the influence of basic sugars in cotton on MVTR. Five replications each of nine fabrics that were developed from the two varieties with the highest and lowest average MVTR (Variety A and J) cultivated in three years (2001, 2002 and 2003) in three different states (Georgia, Texas and Mississippi) were selected. These fabrics were used for the biochemical characterization of carbohydrate oligomers using sequential acid hydrolysis and analysis of the extracts by high pH anion exchange chromatography with pulsed amperometric (HPAEC-PAD) detection of carbohydrates (Dionix Bio LC system with a CarboPac PA-1 column)[17]. This analytical study was carried out by Allen Murray of Glycozyme, Inc., Irvine, CA, USA. The eluent was 150 mM sodium hydroxide, isocratic from 0 to 5 min, then a linear gradient from 0 to 55 mM sodium acetate in 150 mM NaOH with detection using waveform for carbohydrates. Fibers were first extracted with cold water to remove mono and oligosaccharides. Following removal of the cold water extract, the supernatant was extracted with 0.1 N HCl in a boiling water bath then with an aqueous solution of 14.2 N acetic acid and 1.8 N nitric acid (acetic/nitric reagent)[18]. The acetic/nitric insoluble fraction was hydrolyzed further with 2 N trifluoroacetic acid at 100ºC for 2 to 4 hours.

Regression analysis of the fabric MVTR and 46 detected oligomeric and monosaccharide peaks like ribose, iditol, sorbitol, sucrose, verbascose etc., from the four extracts acetic/nitric, TFA hydrolysate, HCL and cold water were conducted using JMP version 5 (SAS). Due to the potential for false positives at the 5% level, only correlations significant at the 1% level were considered. Among all the extracted sugars the water soluble pentasaccharide verbascose was related to MVTR with the following relationship (MVTR = 1425 - 52,950 Verbascose µg/g of fiber; R^2=0.749). This shows lower verbascose is generally preferred to have a higher breathable cotton variety which hitherto has not been reported at all. As is evident from Figure 4, scatter in the verbascose is more pronounced in Variety J compared to Variety A. Preliminary investigations from this study indicate that verbascose might have an influence on, or be a marker for, the moisture vapor transport of cotton fibers. This has to be explored further to have conclusive results on the effect of basic cotton chemistry on the MVTR of cotton fiber.

Although the sample size limits the strength of this study's conclusion with regards to a relationship between Verbascose and MVTR, it does provide additional support for the statement that varietal difference in MVTR may also be due to inherent chemical differences in the fiber and not just the physical attributes of the fiber or its resulting fabric.

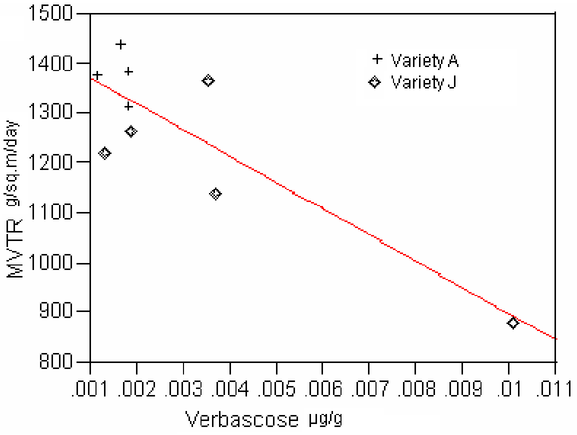

Figure 5. Relationships between MVTR and Verbascose of Variety A and Variety J

Oligosaccharides in cotton play an important role in the development and arrangement of cotton cell wall and hence influence the transport of vapor through them. Murray et al.[19, 20] have shown that sucrosyl oligosaccharides serve as precursor to the cell wall polysaccharides and influence the relative distribution of the cell wall polymers. This clearly shows that the concentration and the distribution of sucrosyl oligosaccharides such as verbascose, may have a role in the development of the cell wall and the cotton fiber development which will influence the transport of vapor across them. The earlier results by Murray et.al.[19, 20] corroborate with the results obtained in this study.

More importantly, Murray et.al.[19, 20] have shown an increase in the concentration of verbascose in cell walls during secondary cell wall biosynthesis. As the thickness of the secondary cell wall increases, resistance to diffusion out of the cell wall of large oligosaccharides, such as the pentasaccharide verbascose, would be expected to increase. Verbascose in cell walls may be a useful marker for breeding cotton varieties with either high or low MVTR. High verbascose concentration in raw fiber or griege fabric could be an indicator of restricted flow during both secondary cell wall biosynthesis and *next-to-skin* cotton comfort as measured by MVTR. This is clearly evident from the negative correlation between the concentration of verbascose and MVTR as shown in Figure 4.

CONCLUSIONS

With the increase in competition from synthetic fibers, the cotton fiber industry has to concentrate on breeding new varieties with enhanced properties. The uniqueness of cotton is its comfort, which enables it to face the challenges from synthetic fibers. The relationship between the breeding origins/pedigree of cotton varieties and the comfort has not been explored heretofore. The study reported in this paper is first of its kind to investigate this relationship, which will help with breeding new varieties with improved comfort and other functionalities. Results show that breeding origin influences the comfort aspect of cotton. Moreover, statistical analysis of data show that MVTR is influenced by variations in cotton varieties that varies in their breeding origin. Data show that MVTR of a transgenic backcross cotton (Variety A) significantly varies from that of a forward cross cotton (Variety J). In addition, Variety A cotton's MVTR was the highest among all other cottons examined. Biochemical analysis of sugar indicated that among oligomers and monosaccharides, verbascose influences the MVTR indicating that the pentasaccharide verbascose may have influence on the breathability of cotton. The content and variability of verbascose for Variety J cotton was higher than those of the Variety A cotton. Lower is the content and variability of pentasaccharide, the better is the MVTR and vice-versa. Cotton breeding programs have so far been aimed at enhancing the yield and the quality of cotton. The work reported in this paper has enabled a paradigm shift and has attempted to link the molecular build-up of cotton to the most important attribute of cotton, its comfort. This part of the study is preliminary and needs further thorough exploration. Such an elaborate study will open-up a new research pathway in cotton breeding for developing functional cottons.

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