Effects of Bulk and Fineness on Thermal Insulation of Egyptian Wool Fabrics

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Abstract: In the present study the Egyptian Barki wool fibers were graded into five grades which are: (G1) coarse fibers with high bulk, (G2) coarse fibers with low bulk, (G3) fine fibers with high bulk, (G4) fine fibers with low bulk and (G5) non-graded fibers (control). Raw, yarn and fabric characteristics were studied to investigate the effect of both bulk and fineness on fabric thermoregulation. Results in this work illustrated that high bulk group with coarse fibers is significantly higher in FD (35.1µ), Med % (13.5), PF (49.4), compared with High bulk group with fine fibers (28.3 µ, 9.2 and 31.1, respectively), while High bulk group with fine fibers tended to be higher significantly in resilience (10.8) and crimp /cm (0.7) compared with High bulk group with coarse fibers (9.7 and 0.5, respectively). Crimpness had a negative correlation with Med% (r = - 0.89), prickle factor (r = - 0.44), thin places, (r = - 0.69) thick places (r = - 0.79) and Neps (r = - 0.75). Grading system was effective in decreasing number of Neps in fine category. Neps correlated significantly (r = 0.77) with thick places, while had no significant correlation with thin places. Effect of fiber types is much important than the effect of bulk in air permeability. Air permeability correlated with irregularity in yarn especially with neps which indicate that fineness is really important to keep Air permeability low and keep body warming. Both studied traits of fineness and bulk affected on thermal insulation.
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Keywords: Bulk, Fineness, Barki wool, Thermoregulation, CLO, Fiber diameter, Neps and TOG.

1. Introduction

Sheep is one of the most important domestic animals in Egypt, its population reaches 5,488,000 heads **(FAO, 2011)**. The most famous Egyptian breeds are: Rahmani which found in the northern delta, Barki which found in the Mediterranean coastal strip, west of Alexandria and Ossimi which found in the south of Nile delta **(El-Hanafy, and Salem, 2009)**. In addition to some sheep ecotypes scattered in some provinces in the valley or in the desert area like: Saaidi, Farafra, Asuiti, Quenawi, Siwa oasis and Al-wadi Al-Jadeed **(Helal, 2000).** All Egyptian breeds produce coarse wool which usually used in producing blankets, carpets and handmade products. Thermal insulation materials like blanket are specifically designed to reduce the heat flow by limiting heat conduction, convection and radiation or all three, which could conserve energy by reducing heat loss or gain as well as control surface temperatures. Moreover, wool fibers are assembled from keratinized cells, which is good insulator for heat. The elongated cortical cells in the center of the fiber are protected from the environment by a layer of cuticle cells. The aim of this study is to discuss the effects of bulk and fineness of wool fibers on thermal insulation of Barki wool blankets.

2. Material and methods

The experimental work was designed to study the extreme variability in loose bulk and fineness of Barki wool fibers and its impact on different performance properties of wool blankets. The Egyptian Barki wool fibers were firstly graded into five grades which are: (G1) coarse fibers with high bulk, (G2) coarse fibers with low bulk, (G3) fine fibers with high bulk, (G4) fine fibers with low bulk and (G5) non-graded fibers (control).

Wool measurements

Fiber diameter (FD) was measured using Image analyzer (LEICA Q 500 MC) with lens 4/0.12. A section of 0.2 mm in length was cut by a hand-microtom at a level of 2cm from the base of the staples of each sample. These cuttings were put on a microscope slide with 2-3 drops of paraffin oil and covered with a slide cover. About five hundred fibers chosen at random were measured from each sample. The mean fiber diameters (FD) together with the standard deviation of fiber diameter (SDFD) were calculated for each sample. While measuring fiber diameter, medullated fibers percentage (fiber contains medulla) as well as prickle factor (the percentage of fibers had greater than 30 µm in diameter) were calculated and recorded for each sample. Loose wool bulk (BUL) and resilience (RES) was measured using WRONZ loose wool Bulkometer **(Dunlop et al., 1974)**. Crimpness (Cr/cm) was obtained for fine and coarse fibers (one crimp = the distance between one bottom or top to the next one).

Yarns specifications

Cotton yarns (20/2 metric) with 11 threads/cm densities were used as warp yarns while wool yarns used as wefts with 2 metric count and 12 weft/cm density. Yarn evenness and hairiness, this test to measure the regularity of the yarn by the following abbreviations: Thin places (- 50%): number of mass reduction of 50% or more in a yarn with respect to the mean value. Thick places (+ 50%): number of mass increase of 50% or more in a yarn with respect to the mean value. Neps (+ 200%): number of mass increase of 200% or more in a yarn with respect to the mean value and reference length of 1cm.

Fabrics structure

All samples are woven as blankets. Weight Test, This test was carried out according to **ASTM**, Standard Test Method for Weight of Textile Materials, **D 3776-96**. A digital balance with 4 digits was used. Five samples (5X5) cm^2 sized were cut from different parts of each sample. The average of all reading was calculated. Thickness test was carried out according to **ASTM**, Standard Test Method for Thickness of Textile Materials, **D 1777-96.** Brightness (L) was measured using Macbeth double beam spectrophotometer (SDL-UK) attached with integrating sphere. The samples were pre-conditioned before testing at standard environment conditions of temperature (20 ± 2 C^o) and relative humidity (65 ± 5%) using standard conditioning room. Air permeability defined as the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. This test was carried out according to **ASTM,** Standard Test Method for Air permeability of Textile Materials, **D 737-96**. Thermal insulation Test was measured according to **ASTM, D 1518-85, Reapproved, 1998**. The thermal transmittance of a fabric or batting is of considerable importance in determining its suitability for use in fabricating cold weather for protection. CLO the unit of thermal resistance is defined as the insulation required to keep a resting man (producing heat at the rate of 58 W/m^2) comfortable in an environment at 21°C, air movement 0.1 m/s. The TOG is a measure of thermal resistance of a unit area. CLO unit is equivalent to 0.155 RSI or 1.55 TOG. Data were statistically analyzed according to **SAS (2001)** using general linear model (GLM) followed by Duncan's multiple range tests to examine the significance classification between means.

3. Results and Discussion

Wool fiber characteristics

Bulk is defined as the volume occupied by a given mass of fibers at a given pressure, while Resilience usually expressed as the ability to absorb work during compression (**Chaudri and Whiteley, 1968 and Dunlop et al., 1974).** High bulk group with coarse fibers (G1) is significantly higher ($P<0.05$) in FD (35.1µ), Med % (13.5), PF (49.4), compared with High bulk group with fine fibers (28.3 µ, 9.2 and 31.1, respectively), while G3 (High bulk group with fine fibers) tended to be higher significantly ($P<0.05$) in resilience (10.8) and crimp /cm (0.7) compared with G1 (9.7 and 0.5, respectively). Bulk found to be associated with high crimp **(Chaudri and Whiteley, 1968)** as well as with high FD **(Carnaby and Elliott, 1980).** Resilience tends to increase as the number of crimps increased **(Roberts and Dunlop1957).** Med % differ significantly between coarse fibers with high bulk and coarse fibers with low bulk (G2), when G2 had 25.9% of Med% compared with 13.5 % for G1 as shown in table and figure (1). **El-Gabbas (1998)** estimated the prickle factor as 45.1 % in the local Barki wool and this value is higher than what found in this study for the control group (G5). Control group values generally located in between the other two groups of coarse and fine fibers. Table (2) shows that fiber diameter correlated significantly and positively with medulla percentage ($r = 0.69$), prickle factor ($r = 0.84$), thin places ($r = 0.74$), thick places ($r = 0.69$) and Neps ($r = 0.54$), while fiber diameter correlated negatively with crimps ($r = -0.80$). Many authors reported that Prickle factor had high correlation with mean fiber diameter **(Abdelaziz and El-Gabbas, 1999; Whiteley and Thompson, 1985 and Hansford, 1992)**. Crimpness had a negative correlation with Med% ($r = - 0.89$), prickle factor ($r = - 0.44$), thin places, ($r = - 0.69$) thick places ($r = - 0.79$) and Neps ($r = - 0.75$). The previous results indicate that the irregularity of wool yarn correlated positively with Med% and prickle factor. Bulk had a strong positive correlation ($r = 0.84$) with resilience.

Wool Yarn characteristics

Helal, et al. (2007) working on camel hair and find that yarn characteristics affected significantly by the characteristics of raw hair after categorized into fine and coarse fibers. The present study found the same results that the variation in FD, Med% and PF had a significant effect ($p<0.05$) on the regularity of wool yarns as shown in table (1).**Gadallah (2007)** reported that differences of fiber types percentage (Fine, Coarse and Kemp) in wool blend affected on yarn homogeneity especially when the percentage of Kemp fibers increased. Also mechanical process itself and exist of small parts of vegetable matter could be affected on yarn regularity **(Emara, 1995)**.

Low wool bulk with coarse fibers (G2) had higher irregularity as expressed in increasing thick places (22.1) and Neps (16.2) compared with high bulk with coarse fibers (12.8 and 10.3, respectively). Thin places was significantly higher (P<0.05) in G1 compared with G3 (60.5 Vs. 34.8), while the highest value was in G2 (76.5) and the lowest value was in control group (12.7). Number of Neps increased in control group compared with fine fibers types which illustrate that grading system is effective in decreasing number of Neps in fine category. Neps correlated significantly (r = 0.77) with thick places, while had no significant correlation with thin places, while both thin and thick places had a strong and positive correlation (r = 0.63).

Fabric characteristics

Fabric weight as found in table (1) decreased in course group compared with the fine one that could be attributed to the presence of medulla in coarse fibers which let course fiber lighter than fine fibers. Table (4) illustrated a highly significant and negative correlation between weight and both of fiber diameter and Med% (r = - 0.70 and - 0.74, respectively). Prickle factor also had a significant negative correlation with fabrics weight (r = - 0.46). Fabric weight correlated negatively and significantly with both of thick places (r = - 66) and Neps (r = - 85). The fabric thickness increased with fine and bulky group compared with the other groups and that could be related to the presence of high crimp in this group as well as high bulk which leads to a high volume of yarns from these fibers, hence, producing thicker fabrics. While the correlation between fabric thickness and wool crimp is not significant (r = 0.27) the trend of correlation as shown in table (4) showed a positive correlation between fabric thickness and both of wool bulk and resilience. Negative correlation was found between the fabric thickness and all characteristics of yarn irregularity (Thin Places, Thick Places and Neps) as well as fiber diameter, Med % and prickle factor. From table (1) it is found that groups of fine fibers (3 and 4) had the highest value of brightness (71.0 of each), while control group (G5) has the lowest value (66.83). Brightness could be affected by the types of medulla and fiber scales which responsible for reflecting lights. Sample of coarse fibers with high bulk has the highest value of yellowness (26.5) followed by coarse fibers with low bulk (25.0). Fine groups with high bulk (21.4) and low bulk (23.09) had the lowest values of yellowness, while control group had a middle value between the fine and coarse groups (24.5). Whiteness takes the opposite trend of yellowness, when fine groups (G3 and G 4) were higher significantly (P<0.05) compared with coarse groups (G1and G2) as shown in table (1). Whiteness had a highly significant positive correlation with brightness (r = 0.61), weight (r = 0.93), thickness (r = 0.65), crimp (r = 0.63), while had a highly significant and negative correlation with yellowness (r = - 0.92), fiber diameter (r = - 0.65), prickle factor (r = - 0.49), Neps (r = - 0.61) as well as significant and negative correlation with Med % (r = - 0.48) and thick places (r = - 0.43). Results in table (4) illustrated that yellowness had a highly and positive correlation with coarse fiber, Med %, Neps and both of thick and thin places. Table (1) shows that in G1 is significantly higher in CLO compared with G2 (7.01 Vs. 4.8 $K.m^2/W$, respectively). The same trend was found in fine fiber groups, CLO was 7.6 $K.m^2/W$ in G3 while, it was 3.6 $K.m^2/W$ in G4. That could explain the important of bulk in thermal insulation. TOG's values show a great advantage for fine with high bulk groups among the other groups. The insulation of fine and bulky group depend on fineness, crimpness and bulkiness effects, that could responsible for the springy behavior of wool fibers, which permits forming a layer of air pockets. This layer of air is effective in the matter of thermal insulation, because it inhibits heat transmittance to and from wool fabrics. This means that insulation made from crimpy wool will retain its thickness, which one of the main contributors to insulation efficiency. On the other hand, coarse fibers contain medulla which plays as an air layer prevent the transition of temperature as well as wool fiber made of keratin, which is a nonconductor material. Tables (3 and 4) illustrated that TOG is significantly correlated with CLO (r = 0.61), thickness (r = 0.70), bulk (r = 0.64), resilience (r = 0.78), which means that warming feeling and thermal insulation increased with the increasing of fabric thickness, fiber fineness, bulky fibers with high resilience. **Vineis et al. (2011)** reported that fine fibers like undercoat preserve the body temperature and cause feeling worm. In the same context, fine fibers of domestic and wild animals which called inner coat produced to help animal keeping body temperature during cold temperature in winter. Table (1) illustrated that air permeability decreased in fine groups (55.5) for G3 and (43.2) for G4, while increased in coarse groups (61.7) in G1 and (62.8) for G2. That means, the effect of fiber types is much important than the effect of bulk in air permeability. Correlation in table (4) support this result when air permeability had no significant correlation with bulk it had a highly and significant correlation with fiber diameter (r = 0.56) and Med% (r = 0.72). Air permeability increased with the increasing of Neps in the yarn (r = 0.62).

Table (1). Means and standard errors of wool fibers, yarns and fabric characteristics among the studied groups

	Traits	**G1**	**G2**	**G3**	**G4**	**G5**	SE
Wool fibers	Bulk	30.4 ^{a}	26.2 ^{c}	30.2 ^{a}	25.4 ^{c}	28.0 ^{b}	0.42
	Fiber Diameter	35.1 ^{a}	36.2 ^{a}	28.3 ^{c}	28.1 ^{c}	31.2 ^{b}	0.91
	Medulation	13.5 ^{a}	25.9 ^{b}	9.2 ^{c}	7.4 ^{d}	18.7 ^{e}	0.29
	Prickle Factor	49.4 ^{a}	45.8 ^{a}	31.1 ^{b}	35.8 ^{ab}	37.7 ^{ab}	4.47
	Resilience	9.7 ^{a}	8.1 ^{b}	10.8 ^{c}	7.9 ^{b}	8.7 ^{d}	0.21
	Crimp	0.5 ^{a}	0.4 ^{b}	0.7 ^{c}	0.7 ^{c}	0.5 ^{a}	0.02
Wool yarn	Thin Places	60.5 ^{a}	76.5 ^{b}	34.8 ^{c}	17.9 ^{d}	12.7 ^{e}	0.28
	Thick Places	12.8 ^{a}	22.1 ^{b}	6.9 ^{c}	12.0 ^{d}	13.0 ^{a}	0.17
	Neps	10.3 ^{a}	16.2 ^{b}	6.3 ^{c}	8.9 ^{d}	16.6 ^{b}	0.16
Fabric	Weight	457.3 ^{a}	460.5 ^{b}	599.3 ^{c}	555.5 ^{d}	442.4 ^{e}	0.15
	Thickness	4.5 ^{a}	4.9 ^{b}	5.4 ^{c}	4.7 ^{b}	4.9 ^{b}	0.06
	Brightness	69.5 ^{a}	70.6 ^{b}	71.0 ^{b}	71.0 ^{b}	66.8 ^{c}	0.28
	Whiteness	-23.2 ^{a}	-15.9 ^{b}	-6.3 ^{c}	-10.6 ^{d}	-19.8 ^{e}	0.13
	Yellowness	26.5 ^{a}	25.0 ^{b}	21.4 ^{c}	23.1 ^{d}	24.5 ^{b}	0.20
	CLO	7.0 ^{a}	4.8 ^{b}	7.6 ^{c}	3.6 ^{d}	11.7 ^{e}	0.02
	TOG	4.5 ^{a}	3.1 ^{b}	11.7 ^{c}	2.3 ^{d}	7.6 ^{e}	0.03
	AIRP	61.7 ^{a}	62.8 ^{a}	55.5 ^{b}	43.2 ^{c}	65.5 ^{a}	1.27

* (G1) Coarse fibers with high bulk, (G2) Coarse fibers with low bulk, (G3) Fine fibers with high bulk, (G4) Fine fibers with low bulk and (G5) Non-graded fibers (control).
* Within a row, means not followed by the same letter are differed significantly (P< 0.05).

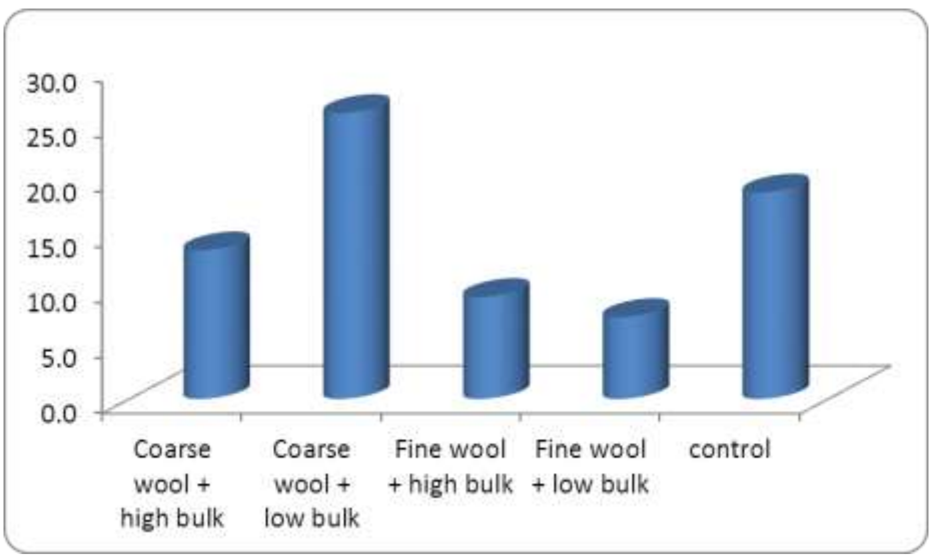

Figure (1). Medullation percentage differences among studied groups.

Table (2). Correlation coefficients of raw wool and its yarn characteristics

	FD	Med%	PF	RES	Crimp	Thin P	Thick P	Neps
Bulk	-0.10	-0.22	-0.24	0.84**	0.05	0.11	-0.51**	-0.37
FD		0.69**	0.84**	-0.19	-0.80**	0.74**	0.69**	0.54**
Med%			0.32	-0.37	-0.89**	0.56**	0.86**	0.88**
PF				-0.16	-0.44*	0.45*	0.40*	0.29
RES					0.26	0.02	-0.66**	-0.56**
Crimp						-0.69**	-0.79**	-0.75**
ThinP							0.63**	0.19
ThickP								0.77**

FD = Fiber diameter, Med% = Medullation percentage, PF = Prickle Factor, RES = Resilience, Thin P= Thin places and Thick P= Thick places. ** P < 0.01, * P < 0.05

Table (3). Correlation coefficients among fabric wool characteristics

	Whiteness	Yellowness	CLO	TOG	AIR P.	Weight	Thickness
Brightness	0.61**	- 0.33	- 0.82**	- 0.15	- 0.58**	0.63**	0.24
Whiteness		- 0.92**	- 0.36	0.39	- 0.61**	0.93**	0.65**
Yellowness			0.07	- 0.56**	0.51**	- 0.86**	- 0.66**
CLO				0.61**	0.63**	- 0.36	0.18
TOG					0.22	0.42*	0.70**
AIR P.						-0.70**	-0.01
Weight							0.54

AIR P. = Air permeability.
** P < 0.01
* P < 0.05

Table (4). Correlation coefficients among raw, yarn and fabric wool characteristics

	Bulk	FD	Med%	PF	RES	Crimp	Thin P	Thick P	Neps
Brightness	- 0.15	- 0.12	-0.31	- 0.01	0.07	0.30	0.35	- 0.02	- 0.59**
Whiteness	- 0.14	- 0.65**	- 0.48*	- 0.49**	0.21	0.63**	- 0.28	- 0.43*	- 0.61**
Yellowness	0.01	0.75**	0.50**	0.60**	-0.28	- 0.67**	0.49*	0.56**	0.54**
CLO	0.46*	-0.04	0.17	- 0.09	0.34	- 0.13	- 0.40*	- 0.29	0.34
TOG	0.64**	- 0.39*	-0.25	- 0.37	0.78**	0.29	- 0.30	- 0.67**	- 0.34
AIRP.	0.38	0.56**	0.72**	0.24	0.21	- 0.72**	0.38	0.36	0.62**
Weight	0.06	- 0.70**	- 0.74**	- 0.46*	0.38	0.78**	- 0.33	- 0.66**	- 0.85**
Thickness	0.08	-0.24	- 0.08	- 0.15	0.39*	0.27	- 0.14	- 0.33	- 0.25

FD = fiber diameter, Med% = Medullation percentage, PF = Prickle Factor, RES = Resilience, Thin P= Thin places, Thick P= Thick places and AIR P. = Air permeability.
** P < 0.01 * P < 0.05

4. Conclusion

Barki wool fibers with high bulk have good thermal insulation ability for fabrics produced from such fibers. Good thermal insulation properties are very important part of textile comfort-ability, which means fabrics ability to transfer perspiration and maintain the body heat. Effect of fiber types is much important than the effect of bulk in air permeability. Air permeability correlated with irregularity in yarn especially with Neps, which indicate that fineness is really important to keep Air permeability low and keep body warming. Both studied traits of fineness and bulk affected on thermal insulation.

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