Relationships among Physical, Chemical and Industrial Characteristics of Different Dromedary Camel's Hair Types

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Abstract: Three hundred kg of raw camel-hair fibers (Magrabi camels) were collected during shearing season from Camel Research Station located in Matroh Governorate. The amount of camel-hair was subjectively classified into four categories control (C1, has no classification), coarse brown fibers (C2), coarser with white fibers liken to wool kemp fiber (C3) and fine fibers (C4). Results indicate that fine camel hair contains higher amount of B, Cd, Co, Cr, Fe, Mn, Ni and S compared with coarse fibers, while coarse fibers had higher Mo, Pb and Zn than fine fibers. Coarse fibers had the highest values of amino acids (THR, SER, GLU, GLY, ALA, VAL, MET, ILE, LEU, TYR, PHE, HIS, LYS, ARG and PRO). Sulfur content of camel hair takes an opposite trend of both MET and CYS with FD, SDFD, B-force, CV of B-force, CV of tenacity, yarn metric count, Twists/meter, twist multipliers and abrasion. Copper, which involved in forming pigments found to be higher in brown coarse categories C1 and C2. Hair bundle elongation reached the maximum in C4 (34.4%), while the lowest percentage found in C3 (4.6%). Category (4) had higher twist multipliers 2.4, 2.5 and 2.6 times those of C3, C2 and C1, respectively. Fine fibers selecting subjectively from the camel-hair fleeces had a good quality as raw material and yarn. More correlations among physical, chemical and industrial characteristics were also discussed.

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1. Introduction

Camel hair is classed as a specialty hair fiber (Anjali and Suman, 2013). Both coarse (strong outer hair) and soft (fine fibers) are found in dromedary camel. Great variations were found among camel fibers not only between flocks and individual animals but also between positions on the same animal. For that, animals used in this study were collected from the same flock and subjected to similar nutritional treatment as well as management system in order to overcome the differences mentioned earlier. The present study aimed to classify subjectively a reasonable amount of camel hair into fine and two types of coarse fibers as well as control category (Has no classification) to shed light on the importance of classification and preparation before using camel hair in the textile industry. Moreover, this classification helps to get very accurate values for the minerals, amino acids content as well as physical and industrial characteristics of coarse and fine fibers which help in making the suitable blends according to the characteristics of individual types of fibers. Also, this study tended to study the correlation among physical, industrial characteristics and chemical content of both fine and coarse camel hair fibers.

2. Material and methods

Three hundred kg of raw camel-hair fibers (Magrabi camels) were collected during shearing season from Camel Research Station located in Matroh Governorate. All camels had the same feeding system and the rations had the same ingredients. Raw camel hair fibers were subjectively classified into four categories as follows:-

Category one (C1): Contained raw camel hair fiber without any classification (control category). Category two (C2): Contained coarse brown fibers of camel hair. Category three (C3): Contained coarse fibers with considerable amount of coarser white hairy fiber liken to kemp wool fiber. Category four (C4): Contained fine camel hair fibers.

Representative sample of each category was used to measure chemical compositions (Minerals and Amino acids), objective measurements of fibers and yarns. Minerals were measured employing Inductively Coupled Aragon Plasma (ICAP6500Duo) and Flame Photometer (PFP7, Jenway, UK instruments) using the methodology by ASTM (2002). Amino acid analyzer (S4300) was used to determine amino acids after hydrolysis the samples according to Pellet and Young (1980) method. Ten representative samples (five hundred fibers in each sample) were taken randomly from each category to measure fiber diameter (FD) using Image Analyzer (LEICA Q 500 MC) with lens 4/0.12. Mean FD and standard deviation (SDFD) were calculated for each category. Hair bundle strength (HBS) in both raw material (HBSr) and scoured (HBSs) materials were estimated by measuring the force required to break the hair bundle in newton then dividing this value by the thickness of the hair bundle

(Ktex). Ten hair bundles were chosen randomly from each category to measure strength using Agritest Staple Breaker (Caffin, 1980). The increase in length as a proportion of the original hair bundle length before testing was used to calculate the hair bundle elongation percentage (HBEL%) according to El-Gabbas et al. (1999). The length of the top as percentage of summed length of both top and base was recorded as point of break (POB) for each category. Hair bundle length (HBL) was measured using a ruler. Metric yarn count (YC) measured as yarns length (m) divided by yarns weight (g). The single yarns were plied at nominal level of 180 (TPM) on "Z" direction (Twists/meter). Twist multipliers (α) is the unit used to compare yarn twist among different yarn count (tex) and it equals number of yarn turns per one meter of yarn with count 1000 tex. (Zellweger Uster) was used to measure both yarn tenacity and elongation. The print out report of previous measurement contains the following abbreviation: B-force = force at break, Elongation % = Elongation when the force at break point is reached, tenacity measured as RKM which is the short expression for Reiss kilometer and it can be expressed as the breaking force of yarn per kilometers at which yarn will break of its own weigh. Yarn samples were used to examine the friction for standard length of yarns as yarn abrasion (Revs). Data were statistically analyzed using one way analysis of variance using General Linear Model (GLM) of SAS (2001) and differences between means were tested using Duncan's Multiple Range Test. Simple correlation coefficients among various traits were also calculated and tested.

3. Results and Discussion

Fiber and yarn characteristics:

In the present study the first category (C1) consisted of raw camel hair without any classification (control category). The second category (C2) contained coarse fibers which had fragmental medulla (Type A), interrupted medulla (Type B) and continuous medulla (Type C) in both white and brown colors (Figures 1 and 2). The third category (C3) contained A, B and C types of medulla and a considerable amount of white fibers which had the same type of medulla found in wool kemp fibers (Latticed medulla) as shown in figure (1) with symbol D. The fourth category (C4) contained fine fiber without medulla in both white and brown colors. Fiber diameter of fine fibers (C4) was 22.4 μ, while control and coarse categories (C1, C2 and C3) had 37. 9 μ, 42.4 μ and 46.4 μ, respectively. Variation among fibers within the same category expressed as standard deviation (SD) showed that C3 had the highest variability followed by coarse category (C2), while minimum SD was found among fine fibers in category C4 that could be due to the variation in medulla diameter which reached maximum value in type D which found in C3. Fine fibers collected from camel fleece could be used as fine textile material with expensive price. Camel hair bundle length of all categories varied significantly ($P<0.05$) among studied categories. The longest hair bundle length was for C2 followed by C3 then C1, while the shortest one was the fine fiber of category (C4). Tender wool located from 20 to 15 N/Ktex, while sound wool located around 30 Ne/Ktex, so all studied categories could be considered as sound hair. Hair bundle strength (HBSs) is more accurate than raw hair bundle strength because raw hair could contaminate with dust and other materials which increased Ktex and consequently decrease bundle strength (Table 1).

Hair bundle elongation reached the maximum in C4 (34.4%), while the lowest percentage found in C3 (4.6%). Position of break located around the middle of the bundle with moderate increase towards the base in both C3 and C4. Fine camel hair had the highest metric count while C3 had the lowest metric count among other categories. Twist multipliers (α) differs significantly among studied categories. Category (4) is higher 2.4, 2.5 and 2.6 times those of C3, C2 and C1, respectively. Force at break proves that camel hair needs to divide into grades because of the great variation found among categories where control category had the lowest B-force among other categories. Category C2 was lower significantly in B-force than fine category C4. Category (3) is the highest one in the B-force and that needs further studies to elucidate this observation especially among fibers with different types of medulla. Control category had the lowest yarn elongation, while C4 was the highest one among studied categories. This proves that classifying camel-hair into categories is a good tool in better characterization of hair than just using it without classification. In the same context, tenacity was found to be high in C4 followed by C3 and C2 then reached the minimum value in C1. Type of medulla is involved in yarns tenacity where fine category had higher tenacity compared with coarse categories. Category (3) found to be the highest one (more than two times) in abrasion among studied categories. The previous result illustrated that homogeneity of fibers involved in yarn structure play an important role in yarn characteristics. The same conclusion was reported by Hunter (1980) who stated that both fiber diameter and its variation play an important role in wool processing. Moreover, Von Bergen (1963) illustrated that fiber diameter might control 80% of spinning process, while fiber length controlled 15% of the product value.

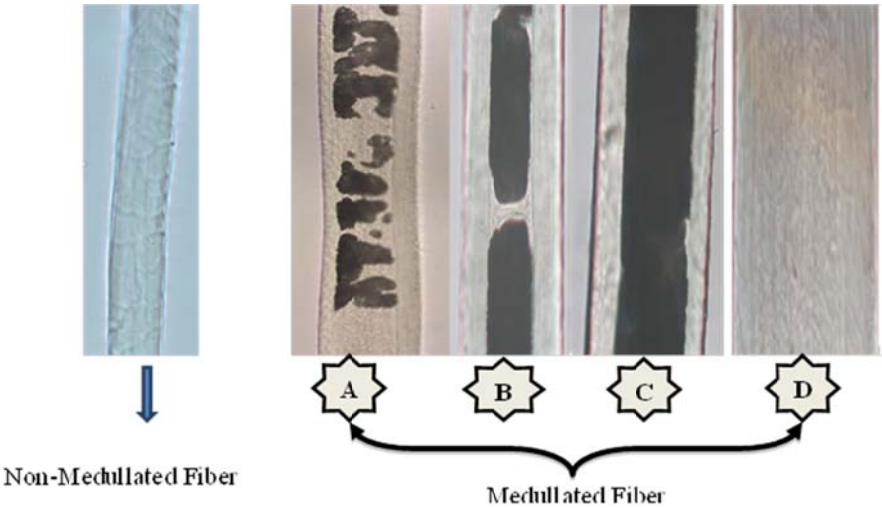

Figure (1). Non-medullated and medullated fibers with white color.

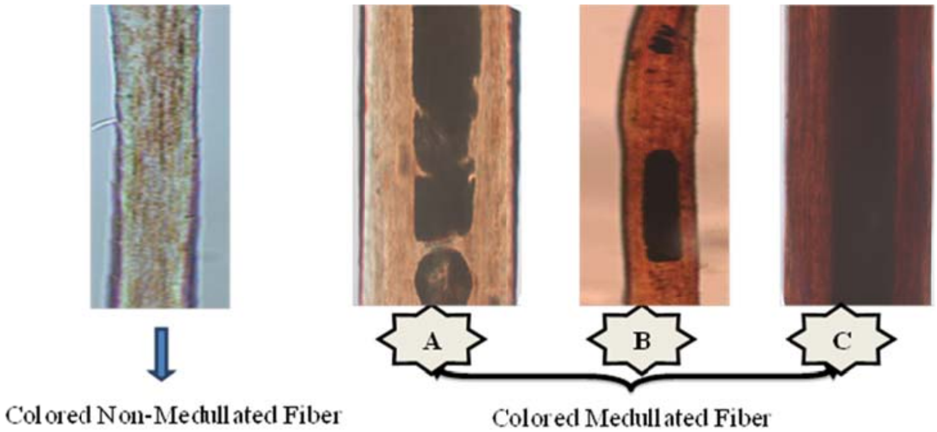

Figure (2). Non-medullated and medullated fibers in brown camel hair.

Table (1). Least squares means and standard errors of physical and industrial characteristics among different type of camel-hair.

TYPE	C1 (Control)	C2	C3	C4	SE
Raw Measurements					
Fiber diameter, FD (µ)	37.89^{a}	42.42^{b}	46.4^{c}	22.36^{d}	0.579
Standard deviation of fiber diameter (SD FD)	13.9^{a}	21.99^{b}	26.4^{c}	6.93^{d}	0.414
Hair bundle length (HBL)	14,45^{a}	17.46^{b}	13.5^{c}	9.31^{d}	0.296
Hair bundle strength raw (HBSr)	42.83^{a}	43.22^{a}	26.0^{b}	27.91^{c}	0.409
Hair bundle strength scoured (HBSs)	46.15^{a}	46.16^{a}	28.1^{b}	29.75^{c}	0.338
Hair bundle elongation (HBEL) %	14.80^{a}	14.77^{a}	4.6^{b}	34.40^{c}	1.052
point of break (POB)	51.88^{a}	49.39^{a}	42.33^{b}	42.36^{b}	1.909
Yarn Measurements					
Yarn count (Metric)	2.81^{a}	2.61^{b}	2.41^{c}	3.01^{d}	0.132
Twists/meter	185^{a}	184^{a}	183^{a}	181.01^{a}	1.428
Twist multipliers (α)	3.71^{a}	3.81^{b}	3.91^{c}	9.51^{d}	0.020
B-force (gF)	346.8^{a}	553.7^{b}	690^{c}	582.91^{d}	0.707
Elongation %	5.69^{a}	8.71^{b}	8.78^{c}	9.46^{d}	0.020
Tenacity (Rkm)	0.98^{a}	1.46^{b}	1.65^{c}	1.75^{d}	0.021
Abrasion (Revs)	43.11^{a}	44.38^{b}	110^{c}	43.01^{a}	0.469

C1= Raw camel hair, C2 = Coarse with brown camel hair fibers, C3 = Coarse fibers with considerable amount of coarser white hairy fiber liken to kemp wool fiber, C4 = Fine camel hair fibers.
Within each row, means not followed by the same letter are differed significantly ($P< 0.05$).

Chemical compositions:

Mclaren and Milligan (1981) reported that protein fiber consists of Carbon (50.5 wt %), Hydrogen (6.8 wt %), Oxygen (22 wt %), Nitrogen (16.5 wt %), Sulfur (3.7 wt %) and ash (0.5 wt %). Although minerals represent only 0.5 wt % in keratin fibers, they could involve significantly on fiber, staple and yarn characteristics. Lee and Grace (1988) reported that while wool contains significant quantities of Calcium, Potassium, Sodium, Zinc, Copper, Manganese, Iron and Selenium, only Copper, Zinc, Iodine and possibly Selenium alter follicle function and wool growth. Table (2) shows highly significant differences among studied categories. Fine camel-hair (C4) had the highest amount of B, Cd, Co, Cr, Fe, Mn, Ni and S compared with other categories. Category 3 was the lowest one containing sulfur among all groups. This could be related to the presence of medulla (The hallow space). The same result was found by Lee and Williams (1996) who stated that fine wool had higher levels of sulfur in wool than strong and medium wool. Coarse camel-hair fibers (C2) had the highest amount of Cu, Pb and Zn among the other types. Control groups (C1) had the highest amount of Al, Si, Sr, V, Ca, Ba, K and Na. Sahoo and Soren (2011) reported that the macro mineral sulfur plays an important role in wool production, while the micro-mineral copper plays a very important role in maintaining quality of wool fiber. Moreover, De-pigmentation of the wool is caused by low activity of the copper containing enzyme tyrosinase. Brown is the common natural color of outer camel hair (which is almost coarse fibers). Table (2) shows that coarse fiber in C2 had the highest amount of copper compared with C3 which had a considerable amount of white coarser fibers and fine fibers which also had a considerable amount of fine white fibers. Human hair had less ash percentage (0.26%) compared with animal fibers (0.5%) because of the differences between food and feed ingredients (Wibowo, et al. 1986). Also, animal hair especially camel hair is a good indicator of pollution because of the high exposure of their feed to soil contamination (Mora, et al. 2000, Medvedev, 1999; Ashurbekov, 1989 and Ray et al. 1997). Rashed and Soltan, (2002) found that Pb was higher in camel hair than in wool and goat hair. In the present study fine camel hair contains higher amount of Cd, Co, Fe, Mn, Ni than coarse fibers, while coarse fibers had higher Mo, Pb and Zn than fine fibers. Table (3) shows that except ASP and CYS category 3 had the highest values of studied amino acids (THR, SER, GLU, GLY, ALA, VAL, MET, ILE, LEU, TYR, PHE, HIS, LYS, ARG and PRO). On the other hand, fine category had the lowest values in all studied amino acids among other categories regardless of ASP. The same result reported by Ibrahim et al. (1978) who found that all amino acids were higher in coarse fiber than in fine fibers.

Table (2). Least square means and standard errors of minerals content among different types of camel-hair.

Minerals (ppm)	Symbol	C1 (Control)	C2	C3	C4	SE
Aluminum	Al	533.1^{a}	485.1^{b}	473^{c}	232.66^{d}	9.885
Boron	B	3.12^{a}	0.88^{b}	0.34^{c}	7.88^{d}	0.168
Cadmium	Cd	0.02^{a}	0.08^{b}	0.02^{a}	0.13^{c}	0.017
Cobalt	Co	0.56^{a}	0.17^{b}	0.32^{c}	1.57^{d}	0.020
Chromite	Cr	36.79^{a}	8.26^{b}	10.6^{c}	92.55^{d}	1.561
Copper	Cu	23.49^{a}	36.24^{b}	11.9^{c}	8.18^{d}	1.001
Iron	Fe	532.4^{a}	565^{b}	554^{c}	1238.7^{d}	13.100
Manganese	Mn	25.25^{a}	18.83^{b}	18.5^{c}	50.29^{d}	2.102
Molybdenum	Mo	2.12^{a}	8.75^{b}	1.1^{c}	5.51^{d}	0.348
Nickel	Ni	18.46^{a}	5.93^{b}	6.73^{c}	81.55^{d}	0.845
Lead	Pb	2.14^{a}	2.81^{b}	1.72^{c}	1.24^{d}	0.425
Silicon	Si	134.3^{a}	28.92^{b}	35.1^{c}	83.46^{d}	2.369
Strontium	Sr	39.95^{a}	32.21^{b}	22.7^{c}	31.51^{d}	2.928
Vanadium	V	0.92^{a}	0.45^{b}	0.5^{c}	0.5^{c}	0.025
Zinc	Zn	120.7^{a}	374.2^{b}	85^{c}	104.67^{d}	4.023
Calcium	Ca	4533^{a}	3895^{b}	2691^{c}	3290.9^{d}	90.737
Barium	Ba	1.57^{a}	0.98^{b}	0.99^{b}	0.99^{b}	0.020
Potassium	K	2247^{a}	1495.4^{b}	1571^{c}	878.68^{d}	15.182
Sodium	Na	588^{a}	194^{b}	196^{c}	196.01^{c}	1.749
Sulfur	S	2936^{a}	4141^{b}	1832^{c}	4843.5^{d}	21.013
Sulfur Percentage	S %	0.3^{a}	0.42^{b}	0.19^{c}	0.49^{d}	0.020

C1= Raw camel hair, C2 = Coarse with brown camel hair fibers, C3 = Coarse fibers with considerable amount of coarser white hairy fiber liken to kemp wool fiber, C4 = Fine camel hair fibers. Within each row, means not followed by the same letter are differed significantly ($P< 0.05$).

Table (3). Least square means and standard errors of amino acids content among different types of camel-hair.

Amino acids (mg/gm)	Symbol	C1 (Control)	C2	C3	C4	SE
Aspartic acid	ASP	87.13[a]	86.96[b]	39.7[c]	69.52[d]	1.444
Threonine	THR	57.74[a]	56.65[b]	62.9[c]	49.29[d]	2.825
Serine	SER	105.9[a]	109[b]	113[c]	84.75[d]	4.577
Glutamic acid	GLU	181.2[a]	184.1[b]	199[c]	147.06[d]	5.910
Glycine	GLY	51.56[a]	49.85[b]	57.3[c]	42.59[d]	2.141
Alanine	ALA	45.04[a]	46.5[b]	48.5[c]	37.48[d]	2.825
Cysteine	CYS	108.2[a]	120.3[b]	116[c]	101.7[d]	4.497
Valine	VAL	53.9[a]	54.77[b]	58.8[c]	45.57[d]	1.846
Methionine	MET	5.2[a]	5.51[b]	5.9[c]	5.09[d]	0.277
Isoleucine	ILE	33.61[a]	33.97[b]	35.9[c]	27.85[d]	1.746
Leucine	LEU	88.47[a]	88.87[b]	97.1[c]	72.73[d]	1.917
Tyrosine	TYR	36.68[a]	35.14[b]	40.9[c]	29.57[d]	0.946
Phenylalanine	PHE	39.34[a]	33.98[b]	42.7[c]	30.6[d]	1.255
Histidine	HIS	15.74[a]	16.24[b]	17.0[c]	13.69[d]	0.775
Lysine	LYS	32.16[a]	33.67[b]	37.2[c]	28.47[d]	1.568
Ammonia	AMMONIA	35.2[a]	36.06[b]	39.9[c]	32.48[d]	1.681
Arginine	ARG	111.9[a]	116.4[b]	122[c]	92.57[d]	3.063
Proline	PRO	62.25[a]	65.17[b]	66.9[c]	53.31[d]	1.239

C1= Raw camel hair, C2 = Coarse with brown camel hair fibers, C3 = Coarse fibers with considerable amount of coarser white hairy fiber liken to kemp wool fiber, C4 = Fine camel hair fibers.
Within each row, means not followed by the same letter are differed significantly (P< 0.05).

Correlation among mineral, amino acids and industrial characteristics of camel hair fibers and its yarn

Sulfur plays a very important role in all keratin fibers characteristics as responsible for disulfide bond (Ryder and Stephenson, 1968). Table (4) illustrates that sulfur had a highly and significant negative correlation with Cd, significant and negative correlation with Al and K, highly significant and positive correlation with B, Co, Fe, Mn, Mo and Ni, while had positive and significant correlation with Cr. Table (5) shows a negative and significant correlation (r = - 0.64) between sulfur content of camel hair and its fiber diameter and that could be related to the increase of medulla volume (defined as hallow space) with increasing fiber diameter. The same result was found by Patkowska et al. (1988) and Boominaton et al. (1983) who reported that sulfur concentration in wool correlated negatively with fiber diameter. Also, Ritchie *et al*. (1999) clarified that addition of sulfur to the diet reduced fiber diameter of wool growth. On the other hand, Gartner and Niven (1978) and Markiewicz et al. (1988) reported that sulfur intake had no effect on sulfur amount in serum and wool. Moreover, several authors stated that there was no relationship between sulfur content of wool and fiber diameter (Piper and Dolling 1966; Reis, 1965 and Doyle et al. 1992).Table (6) shows a highly significant and positive correlation between FD and all amino acids, while PHE had significant correlation with FD. Sulfur containing amino acid methionine and cysteine had highly significant and positive correlation with FD (r = 0.70 and 0.90) and SDFD (r = 0.81 and 0.99), respectively. In the same context, Farzad and Arash, (2013) illustrated that the major nutritional limitation to wool growth is the amount and composition of amino acids available to wool follicles. The supply of sulfur containing amino acids (cysteine and methionine) often limits wool growth and lysine supply is also important. Oddy and Annison, (1979) and Chepelev, (1983) found that methionine plays a specific role in stimulating wool growth. Also, Supplementing sheep diets with rumen protected methionine caused a rapid and dramatic increase in fiber growth (Reis, 1979 and 1988; Masters et al. 1999 and Stewart et al., 1993). Table (5) shows that while sulfur had no significant correlation with B-force and tenacity, a highly significant and positive correlation found between sulfur and CV of both B-force and tenacity. Also, sulfur had negative and significant correlation with twist multipliers (r = - 0.76) and abrasion (r = -0.81) that could be acceptable because of the positive correlation found between FD and both of twist multipliers and abrasion. In the same context, metric count increase with increasing sulfur content and that also could be explained by the negative correlation found between FD and metric count. Methionine had significant and positive correlation with B-force (r = 0.65), highly significant and positive correlation with yarn elongation % (r = 0.72), twist multipliers (r = 0.91) and abrasion (r = 0.87), while had highly significant and negative correlation with yarn metric count (r = -0.95). Cysteine had positive but insignificant correlation with B-force (r = 0.28), significant and positive correlation with yarn elongation % (r = 0.63), highly significant and positive correlation with twist multipliers (r = 0.87) and positive but insignificant correlation with abrasion (r = 0.36), while had highly significant and negative correlation with yarn metric count (r = - 0.84). According to the previous results, methionine could be more effective than cysteine in B-force, yarn elongation and yarn abrasion, while CYS could be more efficient with HBL, FD and SDFD. From the previous results sulfur content of camel hair takes an opposite trend of both MET and CYS with FD, SDFD, B-force, CV of B-force, CV of tenacity, yarn metric count, Twists/meter, twist multipliers and abrasion. For that total sulfur content could be important for some characteristics, while amino acids especially sulfur containing amino acids could be important for some other characteristics. Wool strength tended to increase by adding any sulfur containing compound (Chepelev, 1983; Staples et al. 1993 and Bogdanovic, et al. 1990). On the other hand, Doyle et al. (1992) and Collins et al. (1992) illustrated that neither addition of sulfur nor the mineral lick or methionine had any significant effect on staple strength. In the present study no significant correlations were found between amino acids and both hair bundle strength and yarn tenacity. Al-Betar (2000) found a highly significant and positive correlation between wool strength and leucine, while Ibrahim, et al. (1978) found a negatively significant correlation with Leucine. Merik et al. (1992) and Riley et al. (1991) reported that wool fiber length increased regularly in a group supplemented with the protected methionine. Copper content of camel hair had a highly and positive correlation with Si, Sr, Ca, Ba, K, and Na (Table 4). Iron had significant and negative correlation with Cu, Si, Ba and Na, while had a highly significant and negative correlation with Cd and K. On the other hand Fe had positive and highly significant correlation with Co, Mo, Pb, V, Zn and S. Corbett (1979) illustrated that Cu and Zn are required directly in the process of fiber growth. Moreover, minerals play an important role in sulfur amino acid metabolism because it catalyzes the oxidation of Cysteine to Cystine cross-links during fiber synthesis as reported by Gillespie (1983). Grungreiff (2002) found that, Zinc is required for cell division to occur and it also appears to play a role in protein metabolism. In camel, no obvious trend was found between hair bundle length (HBL) and fiber diameter (FD). Several authors found that wool staple length (STL) had positive correlation with FD (Helal, et al. 2007; Gadallah, 2001; Abd El-Maguid, 2000 and Azzam 1999) and explained that this could be related to the differences of histological meaning between staple and bundle, and because hair fiber usually had higher diameter (regardless of its length) than wool fibers. Also Helal et al. (2010) found that both Damascus and Balady goat had different fiber length with diameter ranging from 67 to 101µ. Yarn twists had significantly positive correlation with fiber diameter (r = 0.60), while had significantly negative correlation with HBL (r = - 0.58). In the same context, Helal et al. (2007) illustrated that FD and SDFD had positive correlation with twists, while no significant correlation found between STL and yarn twists. Fiber diameter and its standard deviation had highly significantly negative correlation with metric count (r = - 0.84). The same result was found by Helal et al. (2007). Table (7) shows that twist multipliers (α) had a positive and highly significant correlation with FD (r = 0.91), SDFD (r = 0.93), and significant with yarn abrasion (r = 0.68), while had highly significant and negative correlation with metric count (r = - 0.93). Yarn abrasion which affected by the scales profile (Ryder and Stephenson, 1968) had a positive but insignificant correlation with FD and SDFD. Negative correlation found between HBL and hair bundle elongation (r = - 0.43) and that could be related to the presence of medulla. A highly significant and positive correlation was found between HBL and yarn elongation (r = 0.83) and that could be related to the structure of yarn which needs longer fiber to form a good yarn. The negative and highly significant correlation was found between HBEL and yarn elongation (r = - 0.70) shows that the structure and fiber behavior in yarn differ than those in hair bundle. Both yarn tenacity and B-force had a significant and positive correlation with HBL (r = 0.64 and 0.61, respectively). In the same context Ryder and Stephenson (1968) reported that yarn strength found to be high with increasing wool fiber length. Moreover, Ince (1979) mentioned that longer wool fibers produced stronger yarn. Both hair bundle strength (HBSr and HBSs) had negatively and highly significant correlation with B-force and tenacity, negatively and significant correlation with yarn abrasion, highly significant and positive correlation with yarn twists. Yarn tenacity had negative and highly significant correlation with yarn twists (r = - 0.97). Yarn abrasion had significantly negative correlation with bundle point of break (r = -0.58), HBEL (r = -0.63) and yarn metric count (r = -0.78). Helal et al. (2008) found the same negative trend between Yarn abrasion and yarn metric count.

Table (4): Correlation coefficients among minerals of camel-hair.

	B	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Si	Sr	V	Zn	Ca	Ba	K	Na	S%	S (ppm)
Al	-0.85**	0.44	-0.77**	-0.86**	0.64*	-0.40	-0.92**	-0.24	-0.94**	0.42	-0.05	0.16	0.27	0.28	0.42	0.50	0.37	0.50	-0.64*	-0.67*
B		-0.47	0.71**	1.00	-0.15	0.21	0.99**	0.15	0.98**	-0.43	0.53	0.34	-0.42	-0.37	0.05	0.02	-0.03	0.01	0.67*	0.70**
Cd			-0.76**	-0.42	0.21	-0.74**	-0.46	-0.75**	-0.45	-0.42	0.07	-0.36	-0.43	-0.47	-0.30	0.24	0.598	0.18	-0.65**	-0.83**
Co				0.67*	-0.48	0.83**	0.73**	0.78**	0.74**	0.30	-0.11	0.22	0.31	0.34	0.06	-0.40	-0.70**	-0.40	0.97**	0.98**
Cr					-0.17	0.15	0.99**	0.08	0.98**	-0.62*	0.53	0.28	-0.49	-0.45	-0.02	0.00	0.01	0.00	0.62*	0.64*
Cu						-0.55*	-0.29	-0.35	-0.34	-0.19	0.70**	0.75**	-0.20	-0.13	0.80**	0.98**	0.73**	0.98**	-0.31	-0.32
Fe							0.25	0.97**	0.26	0.76**	-0.56*	0.04	0.77**	0.77**	0.05	-0.57*	-0.95**	-0.57*	0.80**	0.82**
Mn								0.16	0.98**	-0.43	0.42	0.19	-0.42	-0.38	-0.10	-0.12	-0.11	-0.13	0.67*	0.69**
Mo									0.16	0.83**	-0.47	0.24	0.83**	0.85**	0.27	-0.39	-0.88**	-0.39	0.80**	0.81**
Ni										-0.42	0.38	0.14	-0.41	-0.38	-0.15	-0.17	-0.14	-0.18	0.66*	0.69**
Pb											-0.70**	0.06	1.00**	0.99**	0.26	-0.33	-0.77**	-0.33	0.34	0.34
Si												0.67*	-0.70**	-0.63*	0.50*	0.81**	0.77**	0.82**	-0.03	-0.02
Sr													0.06	0.16	0.95**	0.78**	0.25	0.78**	0.38	0.39
V														0.99**	0.25	-0.33	-0.77**	-0.33	0.35	0.35
Zn															0.34	-0.26	-0.74**	-0.25	0.40	0.40
Ca																0.77**	0.21	0.78**	0.24	0.24
Ba																	0.77**	0.99**	-0.22	-0.25
K																		0.77**	-0.63*	-0.65*
Na																			-0.25	-0.25
S%																				0.97**

Aluminum (Al), Boron (B), Cadmium (Cd), Cobalt (Co), Chromite (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Silicon (Si), Strontium (Sr), Vanadium (V), Zinc (Zn), Calcium (Ca), Barium (Ba), Potassium (K), Sodium (Na), Sulfur (S ppm), Sulfur Percentage (S %). * P < 0.05; ** P < 0.01

Table (5): Correlation coefficients between minerals and industrial characteristics of camel-hair.

	Al	B	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Si	Sr	V	Zn	Ca	Ba	K	Na	S%	S
POB	0.54	0.75**	-0.20	-0.01	-0.20	0.67*	0.08	-0.27	0.27	0.31	0.35	0.28	0.73**	0.34	0.41	0.83**	0.62*	0.11	0.61*	0.38	0.31
HBEL	-0.02	0.41	0.11	0.22	0.43	0.55	-0.04	0.36	0.07	0.32	-0.14	0.63*	0.73**	-0.14	-0.06	0.65*	0.61*	0.28	0.60*	0.32	0.34
HBSr	0.64*	-0.33	-0.25	-0.04	-0.40	0.66*	0.20	-0.45	0.42	-0.49	0.60*	0.09	0.73*	0.60*	0.66*	0.90**	0.55	-0.03	0.56	0.13	0.12
HBSs	0.65*	-0.33	-0.24	-0.05	-0.40	0.67*	0.19	-0.45	0.41	-0.49	0.59*	0.10	0.74**	0.58*	0.65*	0.90**	0.56	-0.01	0.57*	0.12	0.11
HBL	-0.27	-0.14	-0.43	0.54	-0.17	-0.79**	0.86**	-0.05	0.77**	-0.01	0.76**	-0.90**	-0.44	0.76**	0.71**	-0.36	-0.85**	-0.97**	-0.86**	0.45	0.46
FD	0.93**	-0.98**	0.41	-0.69**	-0.99**	0.31	-0.19	-1.00**	-0.09	-1.00**	0.48	-0.42	-0.14	0.47	0.44	0.15	0.14	0.07	0.14	-0.61*	-0.64*
SD FD	0.75**	-0.97**	0.32	-0.53	-0.98	-0.01	0.02	-0.94**	0.06	-0.93**	0.61*	-0.69**	-0.38	0.60*	0.55	-0.08	-0.19	-0.20	-0.19	-0.50	-0.53
B-force (gF)	-0.37	-0.16	0.16	0.05	-0.11	-0.90**	0.19	-0.01	-0.02	0.04	0.04	-0.72**	-0.96**	0.04	-0.05	-0.96**	-0.90**	-0.46	-0.91**	-0.12	-0.13
CV B-force	-0.81**	0.93**	-0.69**	0.90**	0.90	-0.20	0.52	0.92**	0.49	0.91**	-0.08	0.33	0.44	-0.08	-0.02	0.20	-0.07	-0.31	-0.07	0.87**	0.91**
Elongation %	-0.10	-0.43	0.04	0.07	-0.41	-0.82**	0.43	-0.30	0.29	-0.25	0.48	-0.96**	-0.84**	0.48	0.39	-0.72**	-0.90**	-0.69**	-0.91**	-0.05	-0.06
Tenacity (Rkm)	-0.71**	0.24	-0.07	0.43	0.27	-0.97**	0.40	0.38	0.18	0.43	-0.01	-0.57*	-0.77**	0.00	-0.07	-0.87**	-0.91**	-0.58*	-0.93**	0.27	0.25
CV-Tenacity	-0.81**	0.93**	-0.69**	0.90**	0.90**	-0.20	0.52	0.92**	0.49	0.91**	-0.08	0.33	0.44	-0.08	-0.02	0.20	-0.07	-0.31	-0.07	0.87**	0.91**
Yarn Count (Metric)	-0.64*	0.93**	-0.50	0.71**	0.90**	0.12	0.26	0.87**	0.29	0.84**	-0.26	0.61*	0.64*	-0.25	-0.17	0.40	0.27	-0.01	0.26	0.76**	0.76**
Twists/meter	0.85**	-0.45	0.25	-0.57*	-0.48	0.94	-0.44	-0.58*	-0.23	-0.62*	0.08	0.42	0.63*	0.07	0.13	0.78**	0.86**	0.57	0.86**	-0.39	-0.41
Twist Multipliers (α)	0.76**	-0.96**	0.65*	-0.73**	-0.94**	0.05	-0.28	-0.93**	-0.26	-0.91**	0.30	-0.54	-0.48	0.30	0.24	-0.22	-0.08	0.07	-0.10	-0.69**	-0.76**
Abrasion (Revs)	0.22	-0.54	0.72**	-0.69**	-0.47	-0.28	-0.54	-0.45	-0.67*	-0.41	-0.32	-0.34	-0.84**	-0.33	-0.41	-0.76**	-0.32	0.26	-0.33	-0.79**	-0.81**

Aluminum (Al), Boron (B), Cadmium (Cd), Cobalt (Co), Chromite (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Silicon (Si), Strontium (Sr), Vanadium (V), Zinc (Zn), Calcium (Ca), Barium (Ba), Potassium (K), Sodium (Na), Sulfur (S ppm), Sulfur Percentage (S %). Point of break (POB), Hair bundle elongation (HBEL), Hair bundle strength raw (HBSr), Hair bundle strength scoured (HBSs), Hair bundle length (HBL), Fiber diameter, FD (μ), Standard deviation of fiber diameter (SD FD); * P < 0.05; ** P < 0.01

Table (6): Correlation coefficients between amino acids and industrial characteristics of camel-hair.

(mg/gm)	HBSr	HBSs	HBL	FD	SDFD	B-force	CV B-force	Elongation	Tenacity	CV tenacity	Yarn Count	Twists	Twist Multipliers	Abrasion
ASP	0.27	0.28	-0.13	0.95**	0.87**	0.06	-0.98**	0.24	-0.36	-0.98**	-0.89**	0.56*	0.94**	0.62*
THR	0.08	0.08	-0.19	0.86**	0.79**	0.17	-1.00**	0.26	-0.25	-1.00**	-0.91**	0.45	0.93**	0.76**
SER	0.35	0.36	-0.03	0.98**	0.92**	0.05	-0.96**	0.29	-0.36	-0.96**	-0.89**	0.56	0.95**	0.41
GLU	0.22	0.22	-0.07	0.94**	0.89**	0.14	-0.99**	0.31	-0.29	-0.99**	-0.93**	0.49	0.96**	0.66*
GLY	0.04	0.04	-0.22	0.83**	0.76**	0.18	-0.99**	0.24	-0.24	-0.99**	-0.90**	0.44	0.91**	0.78**
ALA	0.30	0.31	0.00	0.97**	0.93**	0.11	-0.97**	0.33	-0.31	-0.97**	-0.92**	0.51	0.96**	0.59*
CYS	0.38	0.37	0.49	0.90**	0.99**	0.28	-0.74**	0.63*	-0.05	-0.74**	-0.84**	0.25	0.87**	0.36
VAL	0.19	0.20	-0.06	0.93**	0.89**	0.16	-0.99**	0.33	-0.26	-0.99**	-0.93**	0.57*	0.97**	0.68*
MET	-0.24	-0.24	0.27	0.70**	0.81**	0.65*	-0.87**	0.72**	0.28	-0.87**	-0.95**	0.32	0.91**	0.87**
ILE	0.29	0.30	-0.08	0.96**	0.89**	0.07	-0.98**	0.27	-0.35	-0.98**	-0.90**	0.25	0.95**	0.60*
LEU	0.18	0.18	-0.10	0.92**	0.87**	0.15	-1.00**	0.30	-0.28	-1.00**	-0.92**	0.48	0.96**	0.69**
TYR	0.05	0.05	-0.24	0.83**	0.75**	0.16	-0.99**	0.22	-0.26	-0.99**	-0.89**	0.46	0.91**	0.77**
PHE	-0.04	-0.03	-0.50	0.67*	0.54	0.04	-0.91**	0.00	-0.34	-0.91**	-0.74**	0.50	0.76**	0.75**
HIS	0.23	0.23	0.02	0.95**	0.93**	0.18	-0.98**	0.39	-0.23	-0.98**	-0.94**	0.45	0.98**	0.65*
LYS	-0.02	-0.02	0.06	0.85**	0.87**	0.39	-0.98**	0.51	-0.03	-0.98**	-0.98**	0.39	0.97**	0.81**
AMMONIA	-0.14	-0.13	0.02	0.78**	0.81**	0.45	-0.97**	0.50	0.03	-0.97**	-0.97**	0.18	0.94**	0.88**
ARG	0.28	0.28	0.02	0.97**	0.93**	0.14	-0.97**	0.36	-0.28	-0.97**	-0.93**	0.49	0.97**	0.61*
PRO	0.32	0.32	0.07	0.98**	0.95**	0.14	-0.95**	0.38	-0.27	-0.95**	-0.92**	0.48	0.97**	0.56

Aspartic acid (ASP), Threonine (THR), Serine (SER), Glutamic acid (GLU), Glycine (GLY), Alanine (ALA), Cysteine (CYS), Valine (VAL), Methionine (MET), Isoleucine (ILE), Leucine (LEU), Tyrosine (TYR), Phenylalanine (PHE), Histidine (HIS), Lysine (LYS), Arginine (ARG), Proline (PRO). Hair bundle strength raw (HBSr) , Hair bundle strength scoured (HBSs), Hair bundle length (HBL), Fiber diameter, FD (μ), Standard deviation of fiber diameter (SD FD); * P < 0.05; ** P < 0.01

Table (7): Correlation coefficients among industrial characteristics of camel-hair.

	HBEL	HBSr	HBSs	HBL	FD	SDFD	B-force	Elongation	Tenacity	Yarn Count	Twists/meter	Twist Multipliers	Abrasion
POB	0.58	0.85**	0.85**	-0.21	0.32	0.11	-0.75**	-0.49	-0.74**	0.22	0.75**	-0.01	-0.58*
HBEL		0.42	0.42	-0.43	-0.32	-0.51	-0.70**	-0.70**	-0.53	0.65*	0.41	-0.55	-0.63*
HBSr			1.00**	-0.05	0.51	0.34	-0.75**	-0.36	-0.79**	0.03	0.79**	0.14	-0.59*
HBSs				-0.07	0.51	0.34	-0.76**	-0.38	-0.80**	0.03	0.80**	0.14	-0.59*
HBL					0.07	0.37	0.61*	0.83**	0.64*	-0.21	-0.58*	0.13	-0.04
FD						0.95**	-0.03	0.28	-0.41	-0.84**	0.60*	0.91**	0.38
SD FD							0.26	0.58*	-0.11	-0.90**	0.32	0.93**	0.46
B-force (gF)								0.89**	0.90**	-0.47	-0.79**	0.30	0.67*
Elongation %									0.74**	-0.61*	-0.59*	0.50	0.52
Tenacity (Rkm)										-0.06	-0.97**	-0.09	0.36
Yarn Count (Metric)											-0.15	-0.93**	-0.78**
Twists/meter												0.33	-0.19
Twist Multipliers (α)													0.68*

Point of break (POB), Hair bundle elongation (HBEL), Hair bundle strength raw (HBSr) , Hair bundle strength scoured (HBSs), Hair bundle length (HBL), Fiber diameter, FD (μ), Standard deviation of fiber diameter (SD FD). * P < 0.05; ** P < 0.01

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