International Design Journal

Volume 10 | Issue 1 Article 35

2020

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Abstract:
This investigation employs a Multi-Criteria Decision Making (MCDM) procedure to derive equation used in ranking the cotton materials regarding yarn evenness (CV %) based on three quality criteria of fiber properties being tensile, fineness and length properties. The weight or relative importance of each criterion is decided by Analytic Hierarchy Process (AHP). The study utilized three Egyptian cotton cultivars being Giza 90, Giza 95 and Giza 86 in addition to three imported cotton cultivars namely; Acala, Kemian and Medling from Sudan, China and Greece, respectively following the Long Staple category. Three yarn counts of 24's, 30's and 36's (Ne) with twist multiplier (4) were applied to produce carded ring yarns. The efficiency of the proposed equation was determined by running Spearman rank correlation coefficients between the yarn evenness (CV %) estimated by the proposed formula and actual yarn evenness (CV %) measured at counts 24's, 30's and 36's Ne. Results revealed that the Egyptian local cultivars were superior to the imported cultivars considering all tested fiber properties. According to the equation derived by AHP method, the power values indicated that the fiber strength, upper half mean length, uniformity index and short fiber index plays an important role in determining yarn evenness (CV %) while the fiber fineness and fiber elongation had low influence. It is obvious that Spearman rank correlation coefficient between the actual yarn evenness (CV %) and that calculated by Analytic Hierarchy Process (AHP) were positive and highly significant indicating the validity of the proposed equation to be applied for ranking cotton materials regarding yarn evenness (CV %).

Keywords:
Fiber Strength
Tensile Properties
Evenness
Fiber Elongation
(MCDM)

Paper received 19th October 2019, Accepted 17th October 2019, Published 1st of January 2020

INTRODUCTION

The quality of final yarn is largely (up to 80%) influenced by the characteristics of cotton materials. However, the level of influence of various cotton fiber properties on yarn quality is diverse and it changes with the yarn manufacturing technology. Besides, the cotton may have conflicting standards in terms of different quality criteria. Therefore, the grading and selection of cotton fibers in terms of different quality criteria will certainly not be the same. This will make the situation more intricate and application of multiple criteria decision making (MCDM) methods can probably deliver a plausible solution. The solution must produce an index of quality value of cotton fiber and the index should incorporate most of the important cotton fiber parameters. The weights of the fiber parameters should commensurate with their importance on the final yarn quality **(Banwet and Majumdar, 2014).**

Majumdar *et al* (2005) compared three traditional methods used to determine technological value of cotton fiber. These methods were fiber quality index (FQI), the spinning consistency index (SCI) and the premium-discount index (PDI), as well as a new method based on a Multiple-Criteria Decision-Making (MCDM) technique. They found that the rank correlation differs widely for the three existing methods. The proposed method of MCDM (multiplicative AHP) could enhance the correlation between the technological value of cotton and yarn strength

Alam and Ghosh (2013) used a multi-criteria decision making (MCDM) approach to evaluate the thermal comfort index of fabrics by considering four decision criteria of fabric parameters such as cover, thickness, areal density and porosity. The weight or relative importance of each criterion is decided by Analytic Hierarchy Process (AHP). They found that the ranking of fabrics by this method yields a reasonable degree of agreement with the ranking based on thermal resistance value.

Duru *et al* (2015) applied a multi-criteria decision making (MCDM) approach to investigate the physical properties of sock fabrics made from some new regenerated fibers such as modal, micro modal, bamboo, soybean, chitosan, cotton and viscose. Their results revealed that the new regenerated fibers, especially the soybean fiber may still be preferred for socks, as they have high abrasion resistance as well as bursting strength, which is important for a garment's lifetime, in addition to their natural antibacterial property.

In Egypt, limited references are available aimed to predict yarn quality properties based on principal components analysis and Multiple-Criteria Decision-Making (MCDM) technique. In this work, an attempt has been made to derive an equation (using the most important cotton fiber properties) employed to determine the cotton yarn quality in term of yarn evenness (CV %).

MATERIALS AND METHODS

The present study utilized three Egyptian cotton cultivars being Giza 90, Giza 95 and Giza 86 in addition to three imported cotton cultivars namely; Acala, Kemian and Medling from Sudan, China and Greece, respectively. The abovementioned cotton materials followed the Long Staple category according to the local practice in Egypt. Six fiber properties and yarn evenness were measured for all used cotton materials using 15 samples taken from season 2018. All fiber and yarn tests were carried out at the laboratories of the Cotton Research Institute, ARC, Giza, under controlled atmospheric conditions of 20 ± 1.1C$^{\circ}$ temperature and 65± 2% relative humidity. The fiber properties were tested according to the following methods:

High Volume Instrument (H.V.I.) instrument system was used to determine: Upper Half Mean Length (mm), Uniformity Index (%), Short Fiber Index (%), Fiber Strength (g/tex), Fiber Elongation according to **(A.S.T.M., 1986 D:4605)**. Meanwhile, Fiber Fineness (mill/tex) was determined by using Micromat tester according to **(A.S.T.M., 1998 D3818-79).** Coefficient of variation of the yarn evenness (C.V. %), were measured by the Uster Evenness Tester III as described by the designation of the **(A.S.T.M., 1984 D-2256).**

The fibers of the used cotton materials were spun to produce carded ring yarns at twist multiplier 4 within three English counts being 24's, 30's and 36's (Ne).

Statistical analysis

To rank the cotton materials in terms of yarn evenness (CV %) using the fibers properties, the collected data were analyzed using the following procedures:

A - Traditional models of analysis

Two statistical models were used to detect the interrelationships among yarn evenness (CV %) under three yarn counts (as response variables) and the fiber properties (as explanatory variables) as follows:

1- Fiber Strength (FS).
2- 2- Fiber Elongation (FE).
3- Fiber Fineness (FF).
4- 4- Upper Half Mean Length (UHML).
5- Uniformity Index (UI)**.**
6- 6- Short Fiber Index (SFI).

A-1- Simple correlation coefficients between each one of the three yarn evenness (CV %) under yarn counts of 24's, 30's and 36's, and each one of the six fiber properties were computed as outlined by **Snedecor and Cochran (1989)**. The simple correlation coefficient computes the linear relationship between two characters ignoring the effects of other characters**.**

A-2- Principal component (PC) analysis is an important approach of multivariate analysis. It was run to give an overall picture about the interrelationships and overlapping among the six fiber properties and yarn evenness, and also for grouping the similar/dissimilar cotton materials. For better visualization, the first two principal components (PC1 and PC2) were graphically plotted against each other using biplot graph (**Gabriel, 2002)**. The graphical presentation of biplot graph will be valid if the principal components 1 and 2 (PC1 and PC) explained the largest part (at least 70%) of the collected data variation.

B- Multiplicative analytic hierarchy process

- Overview of MCDM and AHP

Multiple Criteria Decision Making (MCDM) is a well-known branch of Operation Research, which deals with decision problems involving a number of decision criteria and a finite number of alternatives. The Analytic Hierarchy Process (AHP) introduced by **Saaty (1980, 1983, 1990 and 1994)** is considered one of the most frequently discussed methods of MCDM. The celebrity of AHP may be attributed to it can handle the objective as well as subjective factors, criteria weights and alternatives scores through the formation of a pair-wise comparison matrix, which is the heart of the AHP.

- Hierarchy structure for multiplicative AHP

The goal or objective of the present investigation is to determine the technological value of cotton fiber, which should reflect the yarn evenness. In general, the cotton fiber criteria of this problem can be classified under three headings namely; tensile, length and fineness properties. Tensile properties can be divided into two sub-criteria, fiber strength (FS) and fiber elongation (FE). Similarly, Upper Half Mean (UHML), Uniformity Index (UI) and Short Fiber Index (SFI) are the relevant sub-criteria of length properties to be considered here. Fiber fineness solely represented by m/tex (mic) value. At the lowest level of the hierarchy structure there are the cotton materials as alternatives. The schematic representation of the problem is depicted in Figure (1) **(Majumdar *et al*., 2004 and 2005**).

- Details of AHP methodology

Step 1: To develop the hierarchical structure of the problem, the overall objective or goal of the problem is located at the top of the hierarchy, and the decision alternatives are placed at the bottom. Between the top and the bottom levels there are the relevant attributes of the decision problem such as criteria and sub-criteria. The number of levels in the hierarchy depends on the complexity of the problem.

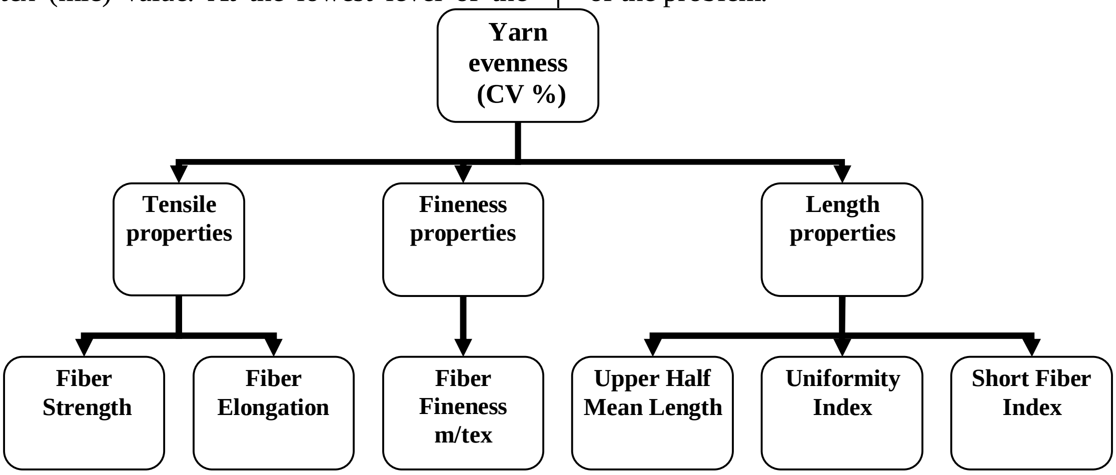

Fig. (1): Hierarchical structure of cotton fiber selection problem.

Step 2: Generate relational data for comparing the criteria and sub-criteria. This requires the decision makers to formulate pair-wise comparison matrices of elements at each level in the hierarchy relative to each activity of the higher level. In AHP, the relational scale of real numbers from (1 to 9) and their reciprocals are used by decision maker to assign his preferences about the problem. When comparing two criteria or sub-criteria with respect to an attribute in a higher level, the relational scale proposed by **(Saaty, 1990)** is used as shown in Table (1).

Table (1): The fundamental relational scale for pair-wise comparisons.

Intensity of importance on	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between two adjacent judgment	When compromise is needed.
Reciprocals	If activity p has one of the above numbers assigned to it when compared with activity q, then q has the reciprocal value when compared with p.	

Step 3: In this stage, the comparisons among the three criteria (tensile, fineness and length properties) with respect to the goal (technological value in term of yarn evenness) are made according to **Saaty** scale as shown in Table (1). The pair-wise comparison matrix of three criteria is given in Table (2). It can be inferred from Table (2) that the dominance of tensile properties over the length properties was of equal importance to the goal (technological value of cotton), while tensile properties were very strongly predominates over the fineness properties. In the context, the length properties demonstrate an extreme preponderance over the fineness properties.

The current matrices were located by the authors to be appropriate for the used cotton materials of Long Staple category. In fact, the past experience of the decision maker plays an important role in building the matrices structure of the AHP method. In the same manner, the pair-wise comparison matrices of sub-criteria with respect to each of tensile and length properties were designed (Table 2).

Table (2): The matrices structure of AHP method.

- Pair-wise comparison matrix of criteria with respect to goal or objective (yarn evenness).

Criteria	Tensile	Length	Fineness	Priority values
Tensile	**1**	**1**	**7**	**0.450**
Length	**1**	**1**	**9**	**0.489**
Fineness	**0.143**	**0.111**	**1**	**0.060**

CR = 0.006 < 0.1.

- Pair-wise comparison matrix of sub-criteria with respect to tensile properties.

Sub-criteria	(FS)	(FE)	NGM	Global weight
Fiber strength	**1**	**9**	**0.9**	**0.405**
Fiber elongation	**0.1111**	**1**	**0.1**	**0.045**

CR = 0.

- Pair-wise comparison matrix of sub-criteria with respect to length properties.

Sub-criteria	(UHML)	(UI)	(SFI)	NGM*	Global weight
Upper Half Mean	**1**	**1**	**2**	**0.399**	**0.195**
Uniformity Index	**1**	**1**	**2**	**0.399**	**0.195**
Short Fiber Index	**0.5**	**0.5**	**1**	**0.201**	**0.098**

CR = 0.00002 < 0.1.

* Normalized geometric mean

- Determining of criteria weights (priority values)

Mathematically, the priority vector of a comparison matrix is corresponding to the normalized Eigen vector of the matrix. Afterwards, it must be check the consistency of the judgment. To do that, we need what is called Eigen value (λ **max**) which was computed by multiplying the comparison matrix by the priority vector to get the products as shown below for the criteria matrix:

$$\begin{bmatrix} 1 & 1 & 7 \\ 1 & 1 & 9 \\ 0.143 & 0.11 & 1 \end{bmatrix} * \begin{bmatrix} 0.450 \\ 0.489 \\ 0.060 \end{bmatrix} = \begin{bmatrix} 1.362 \\ 1.483 \\ 0.179 \end{bmatrix}$$

Now,

$$\lambda \text{ Max} = \left(\frac{1.362}{0.450} + \frac{1.483}{0.489} + \frac{0.179}{0.060}\right) \div 3 = 3.007$$

Then, the consistency index (CI) and consistency ratio (CR) are calculated from the following equations:

$$CI = \frac{\lambda_{max} - N}{N - 1} \quad \text{and} \quad CR = \frac{CI}{RCI}$$

Where RCI is the Random Consistency Index. **Majumdar *et al* (2004 and 2005**) recorded the standard values of RCI as shown in Table 3. If the value of CR equal 0.1 or less, then the judgment is consistent and acceptable. Otherwise, the design maker must be make some changes in the entry of original pair-wise comparison matrix.

Table (3): Random Consistency Index (RCI) values for different numbers of alternative (M) as outlined by **Saaty (1980)**.

M	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

For criteria matrix, the consistency test of the judgment was computed as follows:

$$\text{Consistency Index } (CI) = \frac{3.007-3}{3-1} = 0.003$$

$$\text{Consistency Ratio } (CR) = \frac{\text{Consistency Index } (CI)}{\text{Random Consistency Index(RCI)}} = \frac{0.003}{0.58} = 0.006 < 0.1$$

So, it is considered acceptable

- Determination of sub-criteria relative weights with respect to the corresponding criteria

The pair-wise comparison between sub-criteria of tensile and length properties and the derived weight vectors are shown in Table (2). The global weights of sub-criteria are calculated by multiplying the relative weight of that sub-criterion (FS, FE, UHML, UI and SFI) with respect to the corresponding criterion (tensile and length properties) and the relative weight of that criterion with respect to the goal or objective. For example, the global weight of fiber strength (FS) is 0.9 x 0.450 = 0.405 and so on.

Finally, the efficiency of multiplicative analytic hierarchy process method was determined by conducting Spearman rank correlation coefficients between the of yarn evenness (CV %) values that mathematically derived by AHP methodology and Actual yarn evenness (CV %) measured at counts 24's, 30's and 36's Ne. Minitab (17) statistical software was used to automate the computations of simple and Spearman correlation coefficients as well as principal component analysis while the computation steps required for multiplicative analytic hierarchy process method were programmed using the excel program.

RESULTS AND DISCUSSION

- Fiber properties

The mean values accompanied with the standard deviation of fiber properties were estimated for the six cotton materials and tabulated in Table (4). Results revealed that the local cotton cultivar Giza 86 had the maximum values of fiber strength (FS), upper half mean length (UHML) and uniformity index (UI) recording 45.02, 33.42 and 86.61, respectively. In the same context, the two cultivars Giza 95 and Giza 90 occupied the second and third orders after Giza 86 considering the highest values of above-mentioned three fiber properties. In addition, the three cotton cultivars of Giza 90, Giza 95 and Giza 86 had the lowest values of short fiber index 50 % less than the imported cotton cultivars being Kemian, Acala and Medling. On the other hand, the imported cotton materials of Kemian, Acala and Medling gave the highest values of fiber fineness compared to the Egyptian local cotton cultivars. Accordingly, the Egyptian local cultivars were superior to the imported cultivars considering all tested fiber properties. These results are in harmony with those reported by **Ahmed *et al.* (2014); Hager and Hassan (2016) and Rizk *et al.* (2016)** who showed that cotton materials markedly varied in their fiber technological properties.

Table (4): Mean values of six fiber properties for the used cotton materials.

Cotton materials	Fiber properties (Mean ± SD)					
	FS	FE	FF	UHM	UI	SFI
Kemian	29.05 ± 0.57	5.40 ± 0.25	170.07 ± 4.54	24.97 ± 0.42	73.91 ± 0.58	12.02 ± 0.62
Acala	30.49 ± 0.26	6.20 ± 0.43	175.07 ± 1.94	25.77 ± 1.56	79.31 ± 0.24	10.98 ± 0.58
Medling	34.38 ± 0.36	7.34 ± 0.23	177.53 ± 3.76	27.48 ± 0.29	83.05 ± 0.41	10.15 ± 0.42
Giza 90	37.07 ± 0.53	8.21 ± 0.46	154.87 ± 2.26	30.50 ± 0.33	84.45 ± 1.55	5.64 ± 0.41
Giza 95	37.56 ± 0.64	8.13 ± 0.31	152.00 ± 2.88	30.68 ± 0.51	84.83 ± 1.27	4.92 ± 0.54
Giza 86	45.02 ± 0.52	6.97 ± 0.50	163.80 ± 3.03	33.42 ± 0.62	86.61 ± 0.47	4.23 ± 0.42

Simple correlation coefficients

The simple correlation coefficients between each one of the three yarn evenness (CV %) under yarn count of 24's, 30's and 36's Ne, and each one of the six fiber properties (overall the cotton materials) are shown in Table (5). Generally, it is obvious the similar response of yarn evenness (CV %) for its respective fiber properties under the three yarn counts of 24's, 30's and 36's Ne.

Results showed that the most effective negative and highly significant associations to spinner were those obtained between yarn evenness (C.V. %) and each of fiber strength (-0.96**, -0.92** and -0.97**), upper half mean length (-0.93**, -0.92** and -0.95**) and uniformity index (-0.87**, -0.87** and -0.88**) under the three yarn counts of 24's, 30's and 36's Ne, respectively. Consequently, the lowest yarn evenness (CV %) values would be produced from cotton materials that characterized by highest values of fiber strength, upper half mean length and uniformity index. On the contrary, positive and highly significant associations were obtained between yarn evenness (C.V. %) and short fiber index recording 0.90**, 0.94**and 0.92** under the three yarn counts of 24's, 30's and 36's Ne, respectively. On the other hand, the yarn evenness (C.V. %) was negatively and significantly correlated with fiber elongation while its association with fiber fineness was positive and significant. **Fares *et al* (2010), Hager *et al* (2011) and Hassan and Hager (2014)** who confirmed that spinner must be aware the interrelationships among fiber properties and yarn quality properties.

Table (5): Simple correlation coefficients among three yarn evenness (CV %) and its respective fiber properties overall the cotton materials under three yarn counts.

Fiber properties	Yarn counts		
	24's	30's	36's
Fiber Strength	-0.96**	-0.92**	-0.97**
Fiber Elongation	-0.56*	-0.62*	-0.60*
Fiber Fineness	0.52*	0.63*	0.53*
Upper Half Mean length	-0.93**	-0.92**	-0.95**
Uniformity Index	-0.87**	-0.87**	-0.88**
Short Fiber Index	0.90**	0.94**	0.92**

- Principal component (PC) analysis and Biplot graph

The main goal of using biplot graph is to detect the linear interrelationships among fiber properties and yarn evenness (CV %). Biplot graph explained 93.9 % of the total variation of fiber properties and yarn evenness (CV %) (expressed as standardized data to overcome the different units) for the used cotton materials indicating goodness of fit. The first and two principal components (PC1 and PC2) explained 84.8 % and 9.1 %, respectively.

In biplot graph (Fig. 1), a vector is drawn from the biplot origin to each one of fiber properties to visualize the interrelationships among them. Accordingly, any two fiber properties are positively correlated if the angle between their vectors is an acute angle (< 90°) while they are negatively correlated if their vectors are an obtuse angle (> 90°) and close to 90° reflected no correlation **(Gabriel, 2002)**. Hence, the associations among fiber properties could easily be visualized and interpreted from the biplot graph.

Results revealed that the three fiber properties *i.e.* fiber strength, upper half mean length and uniformity index had strong and positive associations as shown by the small acute angles among their vectors. Also, there were strong and positive associations among short fiber content and the three yarn evenness (CV %) under yarn count of 24's, 30's and 36's Ne as indicated by the small acute angles among them. Meanwhile; there were weak associations among each of fiber fineness and fiber elongation from one side and three yarn evenness (CV %) and other fiber properties from the other side as indicated by near perpendicular vectors among them.

On the other hand, the associations between yarn evenness (CV %) and each one of fiber strength, upper half mean length and uniformity index was strong and negative as shown by the large obtuse angles among their vectors. These results coincided with those obtained by the aforementioned correlation matrix (Table 5) indicating that the biplot graph is a good substitute procedure for correlation coefficients for interpreting the linear interrelationships among fiber and yarn properties.

With respect to the cotton materials, it is appeared from biplot graph (Fig. 1) that the local cultivar Giza 86 was near fiber strength, upper half mean and uniformity index indicating that it is superior the other cotton materials in terms of these fiber properties. Similarly, the highest values of fiber elongation were obtained by the two local cultivars Giza 90 and Giza 95 because their places on the biplot graph were very close. However, the imported cotton materials of Kemian, Acala and Medling occupied the first ranks in term of yarn evenness (CV %) and short fiber index because they were very adjacent. It is worth mentioning that the current results are completely consistent with the abovementioned results of Table (4).

Accordingly, the biplot graph is considered a successful and effective technique beside or instead of tabulated data presentation. Undoubtedly, biplot graph is preferred because it is easy to interpret and more informative. In Egypt, no references have been found about the use of biplot graph for interpreting the interrelationships of fiber and yarn properties.

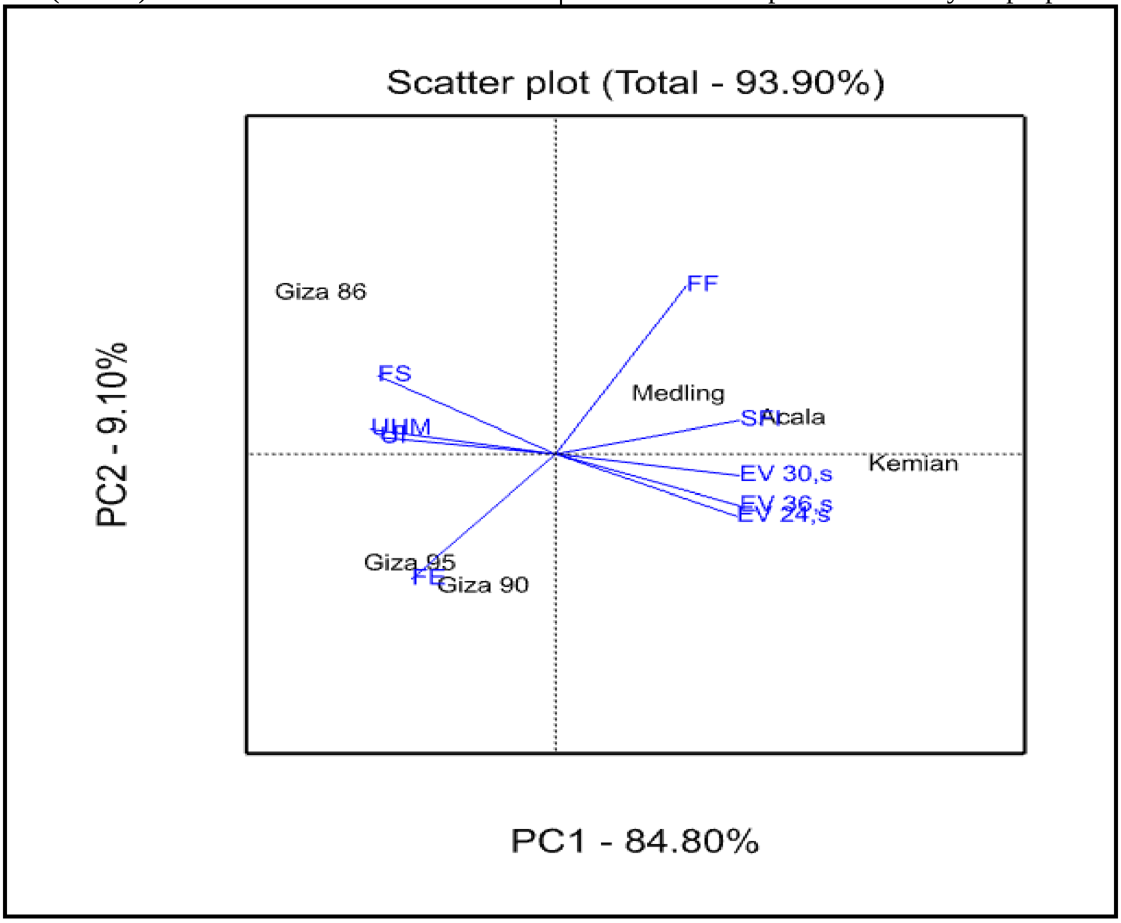

Fig. (1): Biplot graph showing the interrelationships among yarn evenness and their respective fiber properties for 6 cotton materials.

- Estimating the technological value in terms of yarn evenness

Finally, according to the AHP method, it is formulated the following multiplicative model to calculate the technological value in terms of yarn evenness (CV %):

$$\textbf{AHP equation} = \frac{FF^{0.06} * SFI^{0.098}}{FS^{0.405} * UHML^{0.195} * UI^{0.195} * FE^{0.045}}$$

The power values (0.06, 0.098, 0.405 ….) of the sub-criteria at the previous equation represented the priority weights that are estimated using AHP method (Table 2). It is noted that the fiber properties of fiber strength, upper half mean length, uniformity index and fiber elongation were located in the dominator of the proposed model according to their negative relations with yarn evenness (CV %) while the numerator contained the fiber fineness and short fiber index because their positive associations with yarn evenness (CV %) as shown by correlation coefficients in Table 5. The power values (priority values) as regarded in Table (2) indicated that the fiber strength, upper half mean length, uniformity index and short fiber index plays an important role in determining yarn evenness (CV %) with relative weight being 0.405, 0.195, 0.195, and 0.098, respectively while the fiber fineness and fiber elongation had marginal influence on yarn evenness (CV %) with relative weight of 0.06 and 0.045, respectively. To check the calculation steps, the sum of these priority weights must be equal 1. The priority values for the fiber properties according to the multiplicative AHP model were diagrammatically presented in Pie chart as shown in Fig. (2). **Hussein *et al* (2010)** derived an equation using the Multiplicative Analytic Hierarchy Process (MAHP) values to express yarn skein strength (lea product) via fiber properties for the Egyptian cotton varieties.

To validate the equation derived by Multiplicative Analytic Hierarchy Process (MIAHP) approach, Spearman rank correlation coefficients were run between the predicted and actual yarn evenness under the three counts of 24's, 30's and 36's overall the used cotton materials. It was found that the Spearman correlation coefficient between the actual yarn evenness (CV %) and that calculated by Multiplicative Analytic Hierarchy Process (MAHP) were 0.95, 0.96 and 0.97 under yarn counts 24's, 30's and 36's Ne, respectively. Therefore, it can be inferred that thederived equation is reliable and can be applied for ranking cotton materials regarding yarn evenness (CV %). The current conclusions are in parallel line with those reported by **Fares *et al* (2010)**.

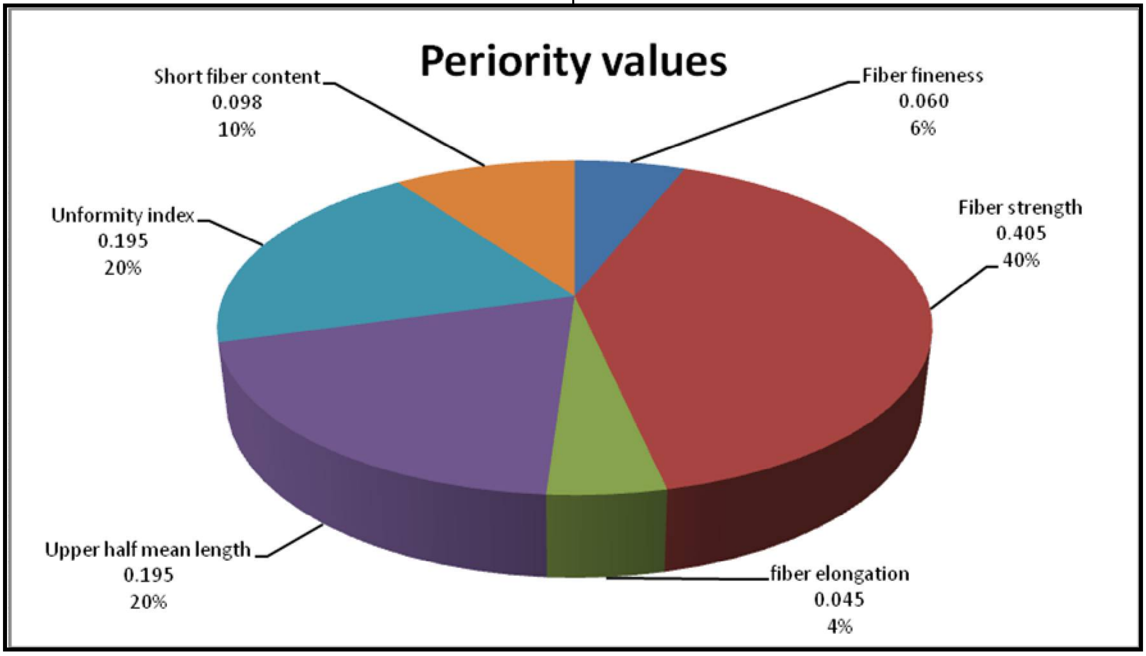

Fig. (2): The priority values for the fiber properties according to the multiplicative AHP model

CONCLUSION

Unconventional method of Multiplicative Analytic Hierarchy Process (MAHP) has been applied to determine the technological value of yarn evenness (CV %) using six fiber properties being fiber strength, fiber elongation, fiber fineness upper half mean length, uniformity index and short fiber index as the decision criteria and their weights (relative importance) are evaluated by Analytic Hierarchy Process (AHP) method. The ranking of yarn evenness (CV %) obtained by the proposed equation shows a good agreement with the ranking based on the actual values of yarn evenness (CV %) under 24's, 30's and 36's Ne. The power values (priority values) of proposed equation indicated that the fiber strength, upper half mean length, uniformity index and short fiber index were the corner stone's in determining yarn evenness (CV %) while the fiber fineness and fiber elongation had weak influence on yarn evenness (CV %). The proposed method is easy and flexible, therefore it can also be extended to determine the quality yarn properties using fiber properties.

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