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The Multiplicative Analytic Hierarchy Process (MI_{AHP}) as a Quality Criterion Determining the Technological Value of the Egyptian Cotton Varieties

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ABSTRACT

This study was undertaken to develop a numerical process that can be used as a quality criterion to determine the technological value of the Egyptian cotton varieties, which in turn would denote the end-use of their fibers. However the material used in the study comprised the 6 Egyptian cotton varieties $Giza_{70}$, $Giza_{80}$, $Giza_{86}$, $Giza_{88}$, $Giza_{90}$ and $Giza_{92}$. According to the local practice in Egypt, $Giza_{70}$, $Giza_{88}$ and $Giza_{92}$ belong to the Extra-Long Staple (ELS) category, while $Giza_{80}$, $Giza_{86}$ and $Giza_{90}$ are included under the Long Staple (LS) category. The regression analysis of the relationships between fiber properties and yarn skein strength (lea product) of the 2 carded ring counts 40 and 50 Ne, was employed to drive an equation for calculating the Multiplicative Analytic Hierarchy Process (MI_{AHP}) values. The values of the MI_{AHP} have been used as numerical determinations of the technological values of the Egyptian cotton varieties. Nevertheless, the findings of this study clarified that with respect to the criteria weights, the pair-wise comparisons denoted that fiber length properties of Egyptian cotton ranked first where they revealed the most dominant effect on yarn strength, while tensile properties ranked second with a relative weight close to that of fiber length. On the contrary, the relative weight of fiber fineness (micronaire reading) was found to be marginal. With regard to the relative weight of sub-criterion, the pair-wise comparisons indicated that the role of fiber tenacity as a determinant of yarn strength is much superior to that of fiber elongation. Further the global weights of the sub-criterion of fiber length pointed out that the UHML (upper half mean length) plays an important role in determining yarn strength of the Egyptian cotton comparing with either the UI (uniformity index) or the SFC (short fiber content). In conformity with the values of the MI_{AHP}, it was found that in the order of descending rank, $Giza_{88}$ ranked first, followed by $Giza_{92}$, $Giza_{70}$, $Giza_{86}$, $Giza_{80}$ and finally $Giza_{90}$.

Keywords: *Analytic Hierarchy Process, Cotton Fiber Quality, Technological Value*

1. Introduction

Cotton is a natural fiber having galore variability in its properties. Most of these properties play a decisive role in determining the tensile characteristics of yarns. Yarn strength, which is considered to be the most important property of spun yarns, is largely influenced by the tenacity, length, length uniformity, short fiber content and fineness (micronaire reading) of the constituent cotton fibers [1]. In fact, the final overall quality of yarn is largely influenced (up to 80%) by the characteristics of raw cotton. However, the level to which various fiber properties influence yarn quality is diverse, and also changes depending on the yarn manufacturing technology. Besides, cotton may have conflicting standards in terms of different quality criteria. Therefore, the ranking or grading of cotton fibers in terms of different quality criteria will certainly not be the same and this will make the ranking of the quality of cotton fibers more complex [2].

The Analytic Hierarchy Process (AHP) is a multicriteria decision making describing which factors are arranged in a hierarchic structure by using a multilevel hierarchical structure of objectives or goals, criteria, subcriteria and alternatives. The principles and the philosophy of the theory give general background information of the type of measurement utilized, its properties and applications. The most creative task in making a decision is to choose the factors that are important for that decision. In the Analytic Hierarchy Process these factors, once selected are arranged in a hierarchic structure descending from an overall goal to criteria, sub criteria and alternatives in successive levels [3].

Analytic Hierarchy Process (AHP) is known to be the most appropriate for solving complicated problems. The AHP is a comprehensive framework that is designed to cope with the intuitive, the rational, and the irrational when making multi-objective, multi-criterion, and multi-actor decisions with and without certainty of any number of alternatives. The basic assumptions of AHP are that it can be used in functional independence of an upper part or cluster of the hierarchy from all its lower parts and the criteria or items in each level [4]. Hence, the AHP is a technique that represents a complex decision problem as a hierarchy with different levels and each level contains different elements with a relevant common characteristic. Using AHP, a cardinal measure of the importance or priority of each element in a level is obtained by pair-wise comparisons of all elements in that level. Each element in level serves as the basis for effecting pair-wise comparisons of the elements in the immediate lower level of the hierarchy. The final priorities of the elements in the lowest level (decision alternatives) are obtained using the principle of hierarchical composition. These lead to the overall ranking of alternatives [5].

Working on the Egyptian cotton Kamal *et al*., [6], pointed out that ranking of the Egyptian cotton varieties by virtue of Fiber Quality Index (FQI) and Staple Ratio (SR) indicated that, as concerns the Extra-Long Staple (ELS) category. $Giza_{87}$ ranked first where it significantly excelled the other varieties of that category. As regards the Long-Staple (LS) category, $Giza_{86}$ variety proved to have the best quality while $Giza_{80}$ ranked last in this category and hence it represented the worst quality among the Egyptian varieties as a whole.

The objective of this study was to ranking or grading the technological value of Egyptian cotton fibers by using the analytic hierarchy process.

2. Material and Methods

The Egyptian cotton varieties $Giza_{70}$, $Giza_{80,}$ $Giza_{86,}$ $Giza_{88}$, and $Giza_{90}$, in addition to the promising hybrid $Giza_{84}$ ($Giza_{74}$ x $Giza_{68}$) which is now known as $Giza_{92}$, were used as a material in the present study. The samples of those varieties were taken from the two successive seasons 2008 and 2009.

The lint cotton samples were spun into the two carded ring yarn counts 40 and 50 (Ne) using the 3.6 twist multiplier.

Fiber upper half mean length (UHML), uniformity index (UI), micronaire reading (MIC), fiber strength (FS) and fiber elongation (FE %) were all determined on the High Volume Instrument (HVI) according to ASTM Designation [7]. Further the Sutter Web Comb Sorter was used to determine short fiber content by weight (SFC %) as directed in the ASTM Designation [7]. Yarn skein strength (lea product) was measured according to ASTM Designation [7].

All fiber and yarn tests were made at the laboratories of the Cotton Research Institute (CRI), Giza, Egypt under controlled atmospheric conditions.

As for the statistical procedures, the correlation and regression analysis according to, Draper and Smith, [8], and the Multiplicative Analytic Hierarchy Process (MI_{AHP}) were used to deal with the data obtained.

Since the Analytic Hierarchy Process is not commonly or widely used and since most of the researchers are not well acquainted with this process, hence, it seems convenient to report on its details according to Majumdar et al. [2], as follows:

Methodology of the Multiplicative Analytic Hierarchy Process (MI_{AHP})

Step 1:

Develop the hierarchical structure of the problem. The overall objective or goal of the problem is positioned at the top of the hierarchy, and the decision alternatives are placed at the bottom. Between the top and bottom levels are found 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 [9-11].

Step 2:

Generate relational data for comparing the alternatives. This requires the decision maker to formulate pair-wise comparison matrices of elements at each level in the hierarchy relative to each activity at the next higher level. In AHP if a problem involves M alternatives and N criteria, then the decision maker has to construct N judgment matrices of alternatives of M x M order and one judgment matrix of criteria of N x N order. Finally, the decision matrix of M x N order is formed by using the relative scores of the alternatives with respect to each criterion. In AHP, the relational scale of real numbers from (1 to 9) and their reciprocals are used to assign preferences in a systematic manner. When comparing two criteria (or alternatives) with respect to an attribute in a higher level, the relational scale proposed by Saaty [11] is used.

The relational Satty's scale is shown below which defines and explains the fundamental relational scale for pair-wise comparisons:

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favour one activity over another.
5	Essential or strong importance	Experience and judgment strongly favour one activity over another.
7	Very strong importance	An activity is strongly favoured and its dominance is demonstrated in practice.
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 step, the relative importance of different criteria with respect to the goal of the problem and the alternative scores with respect to each of the criteria is determined.

For N criteria, the size of the comparison matrix (C1) will be N × N, and the entry c_{ij} will denote the relative importance of criterion i with respect to the criterion j.

n the matrix, $c_{ij} = 1$ if when i = j and $c_{ji} = \frac{1}{c_{ij}}$.

$$c_1 = \begin{pmatrix} 1 & c_{12} & \dots & c_{1N} \\ c_{21} & 1 & \dots & c_{2N} \\ \dots & \dots & 1 & \dots \\ c_{N1} & c_{N2} & \dots & 1 \end{pmatrix}$$

The importance (relative weight) of the **i th** criteria **(Wi)** is determined by calculating the geometric mean **(GM)** of the **i th** row, and then normalizing the geometric means of the rows of the above matrix as follows:

$$\mathbf{GMi} = \left\{\prod_{j=1}^{N} \mathrm{cij}\right\}\mathbf{1/N} \quad \text{and} \quad \mathbf{Wi} = \frac{\mathrm{GMi}}{\sum_{i=1}^{N}\mathrm{GMi}}$$

Then, matrix C_3 and C_4 are calculated such that: $C_3 = C_1 \times C_2$ and $C_4 = C_3/C_2$, where $C_2 = [W_1\ W_2 \dots W_N]^T$.

The principal eigen vector (λ_{max}) of the original pair-wise comparison matrix (C_1) is calculated from the average of matrix C_4.

To check the consistency in a pair-wise comparison judgment, the consistency index **(CI)** and consistency ratio **(CR)** are calculated from the following equations

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

If the value of CR is 0.1 or less, then the judgment is consistent and acceptable. Otherwise the decision maker has to make some changes in the entry of the pair-wise comparison matrix.

RCI is the random consistency index; its value could be obtained from the table below,

RCI values for different numbers of alternative (M)									
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**

[9].

Similarly, N numbers of pair-wise comparison matrices (one for each criterion) of M × M order are formed, where each alternative is pitted against all of its competitors, and pair-wise comparison is made with respect to each of the decision criterion. The eigen vector of each of these 'N' matrices represents the alternative performance scores in the corresponding criterion and from a column of the final decision matrix.

The decision matrix appears as follows:

		Criterion				
		C_1	C_2	C_3	…	C_N
		W_1	W_2	W_3	…	W_N
Alternative	A_1	a_{11}	a_{12}	a_{13}	…	a_{1N}
	A_2	a_{21}	a_{22}	a_{23}	…	a_{2N}
	A_3	a_{31}	a_{32}	a_{33}	…	a_{3N}
	…	…	…	…	…	…
	A_M	a_{M1}	a_{M2}	a_{M3}	…	a_{MN}

Here $\sum_{i=1}^{M} \mathbf{aij} = \mathbf{1}$.

Step 4:

The final priority of all the alternatives is determined considering the alternative scores (aij) in each criteria and the weight of the corresponding criteria (Wj) using the following equation:

$$\mathbf{MI}_{\mathbf{Ahp}} = \mathbf{max}\sum_{j=1}^{N} \mathbf{aij.}\ \ \mathbf{Wj}\ \ \mathbf{for}\ \ \mathbf{i = 1, 2, 3, \ldots, M.}$$

(Multiplicative AHP),

[2].

3. Results and Discussion

3.1. Fiber Quality Properties of Egyptian Cotton Varieties

The data recorded in **Table 1** reveal that the Egyptian cotton varieties involved in this study differ widely with respect to their fiber properties. However, it is worthwhile to mention that according to the local practice in Egypt, $Giza_{70}$, $Giza_{88}$ and $Giza_{92}$ belong to the Extra-Long Staple (ELS) category while $Giza_{80}$, $Giza_{86}$ and $Giza_{90}$ are regarded as Long Staple types (LS). As would be expected, the ELS varieties excelled the LS ones concerning fiber length (UHML), fiber strength (FS) and uniformity index (UI). By contrast, the LS varieties surpassed the ELS as regards fiber elongation (FE), micronaire reading (MIC) and short fiber content (SFC), as shown in **Table 2**. Nevertheless, all the aforementioned fiber properties were used to derive the values of the Multiplicative Analytic Hierarchy Process (MI_{AHP}), which was developed and introduced by Saaty [9-11]. The popularity of the Analytic Hierarchy Process (AHP) lies in the fact that it can handle the objective as well as subjective factors and the criteria weights and the alternative scores are elicited through the formation of a pair-wise comparison matrix which is the heart of the AHP [11] and [2]. However, the following is a figure(**Figure 1**) which clarifies hierarchy formulation for the Multiplicative Analytic Hierarchy Process (MI_{AHP}).

Cotton fiber criteria are classified under three headings, namely tensile properties, fineness properties and length properties. Tensile properties are divided into two sub-criteria, *i.e.* FS (fiber strength) and FE (fiber elongation). Similarly, UHML (upper half mean length), UI (uniformity index) and SFC (short fiber content) are the relevant sub-criteria of length properties. Fiber fineness (FF) is solely represented by the micronaire value (MIC) [1] and [2]. Further, at the lowest level of the hierarchy, there are 6 cotton fiber alternatives or varieties which would be ranked according to their technological value.

Table 1. Range and mean of cotton fiber properties of the studied Egyptian cotton varieties.

Fiber property	Minimum	Maximum	Mean
Upper Half Mean Length (UHML) (mm)	27.1	36.6	32.1
Fiber Strength (FS) (g / tex)	26.0	52.3	41.8
Uniformity Index (UI) (%)	68.0	89.1	84.9
Fiber Elongation (FE) (%)	6.0	8.5	7.0
Micronaire Value (units)	3.0	4.9	4.1
Short Fiber Content (SFC) (%)	2.2	28.6	14.5

Table 2. Averages of fiber properties of the studied Egyptian cotton varieties and the derived values of MIAHP and their descending ranking.

Varieties	UHML (mm)	FS (g/tex)	UI (%)	FE (%)	MIC (units)	SFC (%)	MI_{AHP}	Ranking in conformity with MI_{AHP} value
Extra Long Staple varieties (E. L. S.)								
Giza 70	34.4	45.7	86.9	6.6	4.1	15.1	15.875	3
Giza 88	34.7	47.4	86.5	6.5	3.8	11.2	16.557	1
Giza 92	33.0	46.6	85.9	6.5	3.8	10.9	16.232	2
Average	34.1	46.5	86.5	6.5	3.9	12.4	16.221	—
Long Staple varieties (L. S.)								
Giza 80	30.0	34.9	82.2	7.8	4.3	15.8	13.303	5
Giza 86	32.3	43.9	85.9	7.0	4.4	14.4	15.209	4
Giza 90	28.1	32.6	82.1	7.7	4.0	19.6	12.536	6
Average	30.1	37.1	83.4	7.5	4.2	16.6	13.683	—
Grand Mean	32.1	41.8	84.9	7.0	4.1	14.5	14.769	

UHML: Upper Half Mean Length; FS: Fiber Strength; UI: Uniformity Index; FE: Fiber Elongation; MIC: Micronaire Value; SFC: Short Fiber Content; MI_{AHP}: Multiplicative Analytic Hierarchy Process

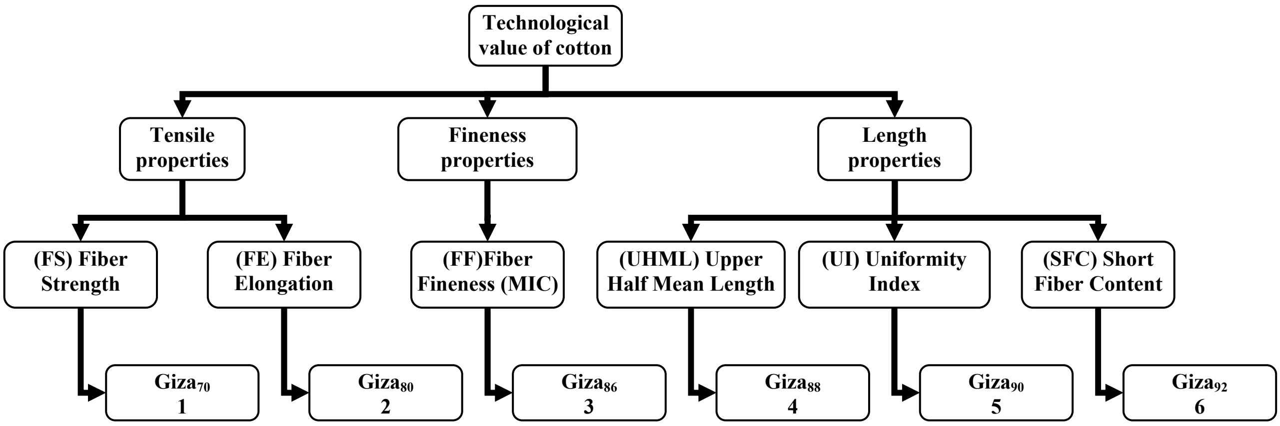

Figure 1.

3.2. Determination of Criteria Weights

The comparisons between the three criteria (tensile properties, fineness properties and length properties) with respect to their relation to the technological value of the Egyptian cotton fibers (the goal) are shown in the pair-wise comparison matrix which is made according to Saaty's scale (**Table 3**).

The normalized geometric mean values (NGM) or weight vector denote that fiber length properties of Egyptian cotton rank first where they reveal the most dominant effect on yarn strength with a relative weight of about 0.489 (NGM). Fiber tensile properties rank second with a relative weight of 0.450, which doesn't differ markedly from that of fiber length properties. On the contrary, fiber fineness relative weight is found to be marginal, *i.e.* 0.059.

For the measurement of consistency of judgment, the original matrix is multiplied by the weight vector (NGM) to obtain the product as follows:

$$\begin{pmatrix} 1 & 1 & 7 \\ 1 & 1 & 9 \\ 0.14 & 0.11 & 1 \end{pmatrix} * \begin{pmatrix} 0.450 \\ 0.489 \\ 0.059 \end{pmatrix} = \begin{pmatrix} 1.356 \\ 1.475 \\ 0.178 \end{pmatrix}$$

$$\lambda \max = \left(\frac{1.356}{0.450} + \frac{1.475}{0.489} + \frac{0.178}{0.059} \right) \div 3 = 3.007$$

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

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

(acceptable).

3.3. The Relative Weights of Sub-Criteria with Respect to the Corresponding Criteria

The pair-wise comparisons between the sub-criteria of tensile properties (FS, FE) and length properties (UHML, UI, SFC) and the derived weight vectors (global weight) are shown in **Table 3**. The global weights of sub-criteria are calculated by multiplying the relative weight of a sub-criterion (FS, FE, UHML, UI and SFC) with respect to the corresponding criterion (tensile properties and length properties) and the relative weight of that criterion with respect to the goal or objective (technological value of Egyptian cotton fibers). For instance, the global weight of fiber strength (FS) is 0.875 × 0.450= 0.394, and of elongation (FE) is 0.125 × 0.450= 0.056. Accordingly, it is quite apparent that the role of fiber tenacity as a determinant of yarn strength is much superior to that of fiber elongation. On the other hand, the global weights of the upper half mean length (UHML), uniformity index (UI) and short fiber content (SFC) were found to be 0.380, 0.054 and 0.054 respectively (**Table 3**). Thus, it is quite evident that the UHML plays an exceptionally important role in determining yarn strength of the Egyptian cotton in comparison with either UI or SFC. With respect to fiber fineness (FF) *i.e.* micronaire value, it is obvious that its role, as previously mentioned is marginal.

3.4. The Technological Value of the Egyptian Cotton Varieties

The values of the Multiplicative Analytic Hierarchy Process (MI_{AHP}) of the Egyptian cotton varieties are demonstrated in **Table 2**. Those values have been regarded to be a quality criterion denoting the technological value of the Egyptian cotton. However, the values of MI_{AHP} were correlated with yarn strength which is in fact the major yarn quality consideration. The values of correlation coefficients were found to be 0.93 and 0.94 for

Table 3. Pair-wise comparison matrices of criteria and sub-criteria.

Pair-wise comparison matrix of criteria with respect to goal or objective.				
Criteria	Tensile	Length	Fineness	Normalized Geometric Mean NGM
Tensile	1	1	7	0.450
Length	1	1	9	0.489
Fineness	0.14	0.11	1	0.059
Consistency Ratio (CR) = 0.006				

Pair-wise comparison matrix of sub-criteria with respect to tensile properties				
Sub-criteria	Fiber Strength (FS)	Fiber Elongation (FE)	NGM	Global weight
Fiber Strength (FS)	1	7	0.875	0.394
Fiber Elongation (FE)	0.14	1	0.125	0.056
Consistency Ratio (CR) = 0				

Pair-wise comparison matrix of sub-criteria with respect to length properties					
Sub-criteria	Upper Half Mean Length (UHML)	Uniformity Index (UI)	Short Fiber Content (SFC)	NGM	Global weight
Upper Half Mean Length (UHML)	1	7	7	0.777	0.380
Uniformity Index (UI)	0.14	1	1	0.111	0.054
Short Fiber Content (SFC)	0.14	1	1	0.111	0.054
Consistency Ratio (CR) = 0					

the 40 Ne and 50 Ne carded ring yarn counts respectively. Those highly significant positive correlations would undoubtedly justify the conception of adopting the use of the MI_{AHP} as an indication of the technological value of the Egyptian cotton varieties. Numerically, the values of the MI_{AHP} as determinants of the technological value of the Egyptian cotton varieties, were calculated from the following equation:

$$\mathbf{CMI_{AHP}} = \frac{\mathbf{FS^{0.394} * UHML^{0.380} * UI^{0.054}}}{\mathbf{FE^{0.056} * FF^{0.059} * SFC^{0.054}}}$$

It seems worthy to note that the presentation of that equation in the previously mentioned formulation was based on the regression analysis between fiber properties and carded ring skein strength at 2 counts, *i.e.* 40 Ne and 50 Ne. Fiber properties taken into consideration are fiber strength (FS), upper half mean length (UHML), uniformity index (UI), fiber elongation (FE), fiber fineness (FF) and short fiber content (SFC). The numerator of the equation comprises fiber properties having positive sign regression coefficients with yarn strength, *i.e.* fiber strength (FS), upper half mean length (UHML) and uniformity index (UI). By contrast, the denumerator includes fiber properties having negative sign regression coefficients with yarn strength, *i.e.* fiber elongation (FE), fiber fineness (FF) and short fiber content (SFC).

Nevertheless, from **Table 2**, it is shown that, in conformity with the values of the Multiplicative Analytic Hierarchy Process (MI_{AHP}) of the Egyptian cotton varieties, and in the order of descending rank, $Giza_{88}$ ranked first followed by $Giza_{92}$, $Giza_{70}$, $Giza_{86}$, $Giza_{80}$ and finally $Giza_{90}$. Accordingly, it is quite apparent that regarding the technological value of the Egyptian cotton varieties, the Extra-Long Staple (ELS) varieties $Giza_{88}$, $Giza_{92}$ and $Giza_{70}$, obviously excelled the Long-Staple (LS) types $Giza_{86}$, $Giza_{80}$ and $Giza_{90}$. This finding is wholly expected, since it is well known that the Egyptian ELS cotton varieties are of higher and better fiber quality characteristics compared with the LS varieties. However, considering all the Egyptian cotton varieties as a whole it could be stated that $Giza_{88}$ is the top quality variety among the Egyptian cottons whereas $Giza_{90}$ ranks last in this respect.

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