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A multi-criteria decision support model for optimal cotton fibre blending

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ABSTRACT
As cotton is a natural fibre, its different physical properties are likely to immensely vary depending on the variations in its seed type, area where it is grown and the climatic conditions. This may affect the characteristics of the final products. Blending is a process of combining different cotton fibres together to synergize their physical properties. For successful blending, it is always required to determine the types of the constituent fibres in the final mix and their appropriate proportions. In this paper, a multi-criteria optimization model in the form of a decision support framework is developed while integrating preference ranking organization method for enrichment of evaluations (PROMETHEE II and V) and geometrical analysis for interactive aid (GAIA) approach. This model is observed to have great potentiality in ranking the considered cotton fibre alternatives from the best to the worst, identifying the top ranked cotton fibres and finding out the constituent fibres in the final blend along with their proportions. Two cotton fibre varieties, such as the Egyptian and Ethiopian types are considered here to demonstrate the applicability of the developed model.

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Cotton fibre; blending; PROMETHEE; net outranking flow; GAIA

1. Introduction

Cotton is a natural fibre having several heterogeneous physical properties influenced by the region where it is cultivated as well as its seed types and variability in the climatic conditions. These variable properties of cotton fibre ultimately affect the quality characteristics of the final products. The main technological challenge in any textile process thus lies in normalizing the high variability in the physical properties of the input cotton fibres while converting them into a uniform end product. This can only be achieved through scientific mixing or blending of the constituent cotton fibres to provide the end products with certain desired characteristics which cannot be obtained from a single cotton fibre. The most popular reason for blending is thus to synergize the variable properties of two or more cotton fibres. Hence, cotton fibre blending enables the production of a homogenous fibre mix, while combining different fibre components so as to attain optimal yarn quality and cost. Thus, cotton fibre blending primarily aims to (a) provide the required characteristics to the end products, (b) compensate for variations in the characteristics of the constituent cotton fibres, (c) reduce the raw material costs and (d) influence favourably the behaviour of the material during subsequent processing.

Depending on the requirements, various types of cotton fibres are used to blend together in different proportions, provided that three basic prerequisites are met, i.e. accurate information about various cotton fibre properties, competent blending machines and consistent fibre profiles. Developments in the cotton fibre selection methods and appropriate blending techniques have mainly been constrained due to lack of accurate and sufficient fibre information resulting from the unavailability of efficient testing methods. In cotton blending process, art and human expertise are generally followed. One of the common techniques is massive blending where large quantities of bales are mixed based on the grade or cultivation area in order to minimize variability. These mixed cottons are again baled and fed to the opening line to further reduce the variability. But, increasing costs of manpower, machinery, material and inventory make this traditional approach of blending almost impractical (El Mogahzy & Gowayed, 1995a, 1995b).

In recent years, availability of more scientific data using high volume instruments (HVI) and advanced fibre information system (AFIS) makes it possible and practical to develop a more dynamic approach for bale management depending on the end product and production requirements, storage space availability, raw material cost and consumption pattern (Fryer, Rust, & Lord, 1996). Thus, the process of cotton fibre selection to facilitate an effective blending procedure while satisfying various end product requirements must undergo an inevitable transition from the traditional art to a sound scientific approach. Cotton fibre selection must be integrated with the blending process that should attempt to optimize the use of the constituent cotton fibres with respect to cost and quality of the final product. The blending process must utilize the information derived from the cotton fibre selection procedure and continuous change in the customer demand patterns. Thus, to have the most effective cotton blending process, five main elements must be integrated together, i.e. development of a cotton fibre database, an effective purchasing policy, testing for determination of the corresponding fibre properties, cotton

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fibre selection and formulation of the cotton mix. Due emphasis must be paid on the deployment of an effective cotton purchasing policy based on the evaluation of the technological value of cotton fibre. The constituent cotton fibres should also primarily meet the technological requirements, i.e. cotton suitable for ring spinning may not be appropriate for rotor or air-jet spinning. Similarly, for a particular spinning method, other factors, like yarn count, yarn tenacity, twist, etc., also dictate the type and proportion of cotton fibres in a blend. Consistency of the cotton fibre profiles in a blend, thus becomes a pivotal issue in determining blend uniformity and attaining process stability while having uniform yarn qualities.

2. Literature review

Kang, Park, Koo, and Jeong (2000) presented a frequency-relative picking method based on HVI quality index for cotton bale selection and lay down formation to improve lay down uniformities. Majumdar, Sarkar, and Majumdar (2006) proposed a novel approach for cotton fibre grading and subsequent selection using the technique for order preference by similarity to ideal solution (TOPSIS). Mohamed and Abd-Ellatif (2008) developed a multi-regression-based methodology for predicting the properties of the blended cotton fibres based on those of the individual components and blending proportions. Sheikh and Lanjewar (2010) designed a decision support system to optimize the cotton bale blending/mixing process while reducing the overall cotton cost subject to some predetermined quality constraints. Majumdar, Mangla, and Gupta (2010) developed a decision support system for cotton fibre grading and selection for subsequent application in spinning industries. Nisarahmed and Agrawal (2011) pointed out that selection of the right constituents and their proportions in a cotton fibre blending process would really be a brainstorming exercise, involving mathematical knowledge and human intelligence. Ghosh, Majumdar, and Das (2012) applied *k*-mean square clustering algorithm for effective cotton bale management. It was concluded that clustering of bales into different categories would help in preparing consistent bale mix for subsequent lay down. Chakraborty and Bandhopadyay (2017) integrated preference ranking organization method for enrichment of evaluations (PROMETHEE) and geometrical analysis for interactive aid (GAIA) approach for solving a cotton fibre selection problem. The PROMETHEE II method ranked all the considered cotton fibre alternatives depending on their net outranking flows and GAIA tool provided a visual aid for grading of those fibres to support the blending process. From the above-cited review of the existing literature, it becomes quite apparent that since several years, cotton fibre selection and grading has been a major topic of research, and various multi-criteria decision-making (MCDM) tools have been successfully adopted to resolve this problem. An MCDM problem usually deals with selection of the best suited alternative in presence of several conflicting criteria. Using those MCDM methods, cotton fibres were chosen based on their physical properties to aid the subsequent ring spinning process. Some mathematical tools, like linear programming (LP) method was also employed to determine in which proportion the selected cotton fibres should be blended to meet the end product requirements, mainly based on the cost criterion. In this paper, two varieties of cotton fibres, i.e. Egyptian and Ethiopian types are considered from which the most appropriate groups of fibres are subsequently selected to aid the blending process so as to fulfil some of the end product requirements. In both the cases, the PROMETHEE II method is first applied to rank the considered fibre types from the best to the worst based on their some important physical characteristics. The developed GAIA plane helps in segregating those fibre types into different groups/clusters with almost similar property profiles. Those shortlisted cotton fibre types would be the constituents of the final blend. Finally, PROMETHEE V method is adopted to determine the proportions of the constituent fibres in the blend based on their net outranking flow values. As this integrated approach depends on an aggregated measure of various properties of the blend components, it would help the spinning industry personnel in determining the more accurate and realistic proportions of the constituent cotton fibres in a blend. Thus, in this paper, PROMETHEE method is implemented so as to develop a multi-criteria optimization model focussed at determining the optimal mix of the constituent fibres in a cotton blend.

3. PROMETHEE-GAIA method

Amongst various MCDM tools, the PROMETHEE method (Brans & Vincke, 1985) has become quite popular within the decision-making community because it has a clear computation procedure and can easily be interpreted for the purpose of decision-making. It is also one of the most employed outranking methods in practice. The PROMETHEE family of methods has several versions, such as PROMETHEE I, II, III, IV, V and VI. The PROMETHEE I method provides a partial ranking of the candidate alternatives, PROMETHEE II allows a complete ranking, PROMETHEE III provides an interval order emphasizing indifference, PROMETHEE IV deals with continuous sets of possible alternatives, PROMETHEE V includes segmentation constraints and PROMETHEE VI is adopted when precise weights are not allocated. The PROMETHEE method can also be combined together with the principal component analysis approach in the form of GAIA plane which acts as a visualization tool for investigating the results derived from the multi-criteria analysis (Brans & Mareschal, 1994; Mareschal & Brans, 1988).

The PROMETHEE II is a non-parametric MCDM method used to evaluate and rank a number of candidate alternatives with respect to some predefined criteria/attributes (Rao & Patel, 2010). It is primarily based on the outranking principle aimed to determine the degree of dominance of one alternative over another within a set of feasible options A ($a_i \in A$, for $i = 1,2, \ldots, m$) with respect to jth criterion (for $j = 1,2, \ldots, n$). The dominance degree is estimated while comparing pairs of alternatives from a set of alternatives A, and is based on the value x_{ij} which denotes the relative performance of ith alternative against jth criterion. A preference function is usually associated with each criterion for each pair of alternatives in order to reflect the perception of the decision-maker. Thus, for each criterion, the following preference function is considered:

$$\begin{aligned} &p_j(a,b) = F_j[\mathrm{d}_j(a,b)] \quad \forall a,b \in A \\ &\text{where} \quad \mathrm{d}_j(a,b) = [f_j(a) - f_j(b)], \quad 0 \le p_j(a,b) \le 1. \end{aligned} \tag{1}$$

When the deviations are negative, this preference becomes zero. The value of $p_j(a,b)$ is a number between 0 and 1, and it signifies the degree of preference that the decision-maker expresses for *a* over *b* with respect to *j*th criterion. Now, the aggregated preference indices are expressed as below:

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{n} p_j(a,b)w_j \\ \pi(b,a) = \sum_{j=1}^{n} p_j(b,a)w_j \end{cases} \quad (2)$$

where $\pi\,(a, b)$ is the degree with which alternative *a* is preferred to *b*, $\pi\,(b, a)$ is the degree with which alternative *b* is preferred to *a* and w_j is the relative importance or priority weight allocated to *j*th criterion. These criteria weights can be determined while employing analytic hierarchy process (AHP) (subjective assessment based on pair-wise comparison of the criteria values) (Saaty, 1980) or Shannon's entropy method (Rao, 2007) (objective assessment considering the degree of disorder in a system). From these aggregated preference indices, two outranking flows can be defined. The positive outranking flow (leaving flow), as given in Equation (3), is the measure of strength of an alternative *a* with respect to the others. On the other hand, the negative outranking flow (entering flow) estimates the weakness of alternative *a* with respect to others, as expressed in Equation (4).

$$\text{Positive outranking flow, } \varphi^{+}(a) = \frac{1}{m-1}\sum_{x\in A}\pi(a,x) \quad (3)$$

$$\text{Negative outranking flow, } \varphi^{-}(a) = \frac{1}{m-1}\sum_{x\in A}\pi(x,a) \quad (4)$$

The net outranking flow is finally calculated while balancing between these two outranking flows:

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \quad (5)$$

A higher value of $\varphi(a)$ always signifies a better course of action or option. Thus, the PROMETHEE II method ranks the alternatives on the basis of their net outranking flows. Behzadian, Kazemzadeh, Albadvi, and Aghdasi (2010) provided an excellent review of PROMETHEE II method and its applications in diverse decision-making domains.

The GAIA helps as a visualization tool to complement the complete ranking preorder as derived using PROMETHEE II method and provide guidance regarding the impact analysis of the most important criterion in the developed model. The GAIA plane represents the projections of a set of *n* alternatives as a cloud of *n* points in a *k*-dimensional space (*k* is the number of criteria). In this plane, the positions of the alternatives determine their strengths and weaknesses with respect to various criteria. Similarly, based on the positions of the criteria in this plane, concord or conflict between them can be identified. The positions of different criteria also provide valuable information regarding the significance of each criterion in the process of ranking of the alternatives in a developed model. For each alternative, the corresponding 'bonus' and 'penal' criteria can easily be identified. In the GAIA plane, the alternatives having similar property profiles are clustered into different groups which would be quite helpful in segregating a set of cotton fibre varieties into similar groups to aid the subsequent blending process.

The implementation of PROMETHEE V approach extends the application scope of PROMETHEE II method (Brans & Mareschal, 1992). The PROMETHEE II method usually provides a single compromise solution. On the other hand, PROMETHEE V method deals with those decision-making problems where several options need to be selected while satisfying a given set of constraints. It is particularly useful when the set of alternatives is segmented, and should be verified both between and within the cluster. In this paper, PROMETHEE V method is adopted following the two steps as provided below:

Step 1: At first, a cotton fibre selection problem is considered without any constraint. For each cotton fibre alternative, the net outranking flow is calculated using Equation (5).

Step 2: The corresponding optimization model is then developed in the form of LP problem taking into consideration the net outranking flow values and a predefined set of constraints on certain criteria. The objective function of this optimization model is expressed as below (Nikolić, Jovanović, Mihajlović, & Živković, 2009; Savic et al., 2015):

$$\text{Max} \sum_{i=1}^{m} \varphi(a_i)\, X_i \quad (6)$$

where *m* is the number of X_i cotton fibre constituents considered for blending.

In this paper, two major varieties of cotton fibre, i.e. Egyptian and Ethiopian types are considered. For each variety, different cotton fibre types with varying physical properties are treated as the candidate options from which the top ranked cotton fibres are first identified as the feasible constituents for the subsequent blend. The PROMETHEE V method is subsequently employed to determine the proportions of the component fibre types in the blend while aggregating all their physical properties. In this proposed multi-criteria optimization model, the following four research scenarios are taken into account:

(1) Scenario 1: application of the model considering subjective assessment of the importance of the considered criteria (criteria weights are calculated using AHP method),
(2) Scenario 2: application of the model considering objective assessment of the importance of the criteria (weights are calculated using entropy method),
(3) Scenario 3: application of a modified version of scenario 1 with the addition of price criterion in the decision-making model, and
(4) Scenario 4: application of a modified version of scenario 2 with the addition of price criterion in the model.

The applications of scenarios 3 and 4 would thus highlight the importance of the economic aspect in the multi-criteria analysis of the cotton fibre blending process.

4. Illustrative examples

4.1 Egyptian variety

In this example, seven different cotton fibre types under the Egyptian variety, i.e. Giza 70, 86, 87, 88, 90, 92 and 93 are considered. The Egyptian cottons, mainly grown alongside the Nile River, are famous for their higher staple length and silky texture (El Messiry & Abd-Ellatif, 2013). They have smaller diameters, but their bundle strength is superior to other cotton fibres. Table 1 exhibits the detailed physical properties of the considered Egyptian cotton fibre types. Amongst these properties, reflectance (Rd%), upper half mean length (UHML), uniformity index (UI), fibre bundle strength (FS) and fibre elongation (FE) are the higher-the-better type of quality characteristics. On the other hand, yellowness (+b), short fibre index (SFI), fibre fineness/micronaire (MIC) and cotton price (in USD/kg) are the lower-the-better type of quality characteristics. The last two rows of this table respectively provide values of the arithmetic mean and coefficient of variation (CV%) for these fibre properties. It is interestingly noticed that cotton fibre price has a direct relationship with UHML. Now, in order to determine the relative significance of each cotton fibre property in this multi-criteria optimization model, AHP and entropy methods are separately employed under the four considered scenarios. Under scenarios 1 and 2, criteria weights are subjectively and objectively determined without considering the prices of the Egyptian cotton fibre types. On the other hand, under scenarios 3 and 4, these weights are again evaluated taking into account the related cotton fibre prices. These calculated weights are provided in Table 2 for different scenarios. With the introduction of the additional economic criterion, in scenario 3, almost 40% significance is assigned to this criterion, whereas, in scenario 4, it has only 11% significance. This variation in the relative significance of the price criterion mainly occurs due to the subjectivity and biasness inherent in AHP method while comparing different criteria pairwise. Furthermore, in this table, the stability intervals of all the estimated criteria weights are exhibited. These intervals signify that within which bounds the weight of each criterion can be varied without affecting the PROMETHEE II ranking results for each of the considered scenario. It is worthwhile to mention here that these weights are varied only for one particular criterion, while the relative weights of the other criteria remain the same. These criteria weight stability intervals are derived from the PROMETHEE-GAIA software which can be downloaded from www.promethee-gaia.net/software.html website.

Now, adopting the procedural steps of PROMETHEE II method, the net outranking flow values for all the cotton fibre types under the considered scenarios are computed, as shown in Table 3. It is observed that in both the scenarios 1 and 2, Giza 87 is identified as the most suitable Egyptian cotton fibre type. In scenario 1, Giza 87, 93 and 92 form the best performing group of cotton fibres, and in scenario 2, the top performing group of fibres remains the same with Giza 93 and 92 just interchanging their ranking positions. Thus, it may be concluded that without the economic consideration, the subjective and objective approaches of criteria weight measurement have little impact on the relative positions of the top three alternative cotton fibres. In scenario 1, Giza 90 is the worst performing fibre type and it occupies the last but one position in the fibre ranking list in scenario 2. A clear understanding about the property profiles of different Egyptian cotton fibre types under scenario 1 can be obtained from the PROMETHH rainbow diagram, as shown in Figure 1. From this figure, it can be observed that Giza 87 (G_3)

Table 1. Physical properties of the Egyptian cotton fibre types (Tesema & Hussein, 2015).

Property									
Type	Rd%	+b	UHML	UI	SFI	FS	FE	MIC	Price
Giza 70 (G_1)	74.58	9.59	34.41	86.45	9.79	46.23	6.40	4.16	4.18
Giza 86 (G_2)	75.80	9.11	33.11	86.40	9.62	43.94	6.46	4.51	4.08
Giza 87 (G_3)	75.08	9.40	36.00	87.15	9.59	47.23	6.36	3.14	4.30
Giza 88 (G_4)	66.78	11.85	35.38	86.33	9.55	46.86	6.15	4.15	4.22
Giza 90 (G_5)	67.36	11.98	29.39	85.11	10.49	33.43	7.63	4.13	4.01
Giza 92 (G_6)	74.63	8.78	33.91	86.73	9.77	47.49	6.33	3.91	4.10
Giza 93 (G_7)	65.89	11.68	36.14	87.23	9.79	46.35	6.61	3.16	4.34
Mean	71.44	10.34	34.05	86.48	9.80	44.50	6.56	3.88	4.18
CV%	6.32	13.02	6.55	1.38	5.61	10.87	7.93	13.41	2.89

Table 2. Weights and their stability intervals for the properties of the Egyptian cotton fibre types under different scenarios.

Property	Scenario 1 (Subjective weight)		Scenario 2 (Objective weight)		Scenario 3 (Subjective weight)		Scenario 4 (Objective weight)	
Rd%	0.0302	0 0.1640	0.1625	0.1036 0.1660	0.0228	0 0.0312	0.1440	0.0611 0.2033
+b	0.0302	0 0.1640	0.1879	0.1307 0.1954	0.0228	0 0.0475	0.1662	0.1382 0.2581
UHML	0.3256	0.1970 0.4631	0.0759	0.0697 0.1318	0.1825	0.1733 0.2049	0.0672	0.0358 0.1567
UI	0.0951	0 0.3790	0.0772	0.0695 0.1827	0.0612	0.0532 0.0781	0.0684	0.0371 0.1775
SFI	0.0734	0 0.2085	0.0700	0 0.0861	0.0493	0.0298 0.0685	0.0620	0 0.1661
FS	0.2625	0.0084 0.3922	0.0685	0.0533 0.1328	0.1531	0.1310 0.1787	0.0607	0.0319 0.2088
FE	0.0346	0 0.1993	0.2144	0.1879 0.2612	0.0257	0.0130 0.0432	0.1900	0.0746 0.2156
MIC	0.1487	0 0.3328	0.1436	0.1375 0.3149	0.0910	0.0853 0.1180	0.1272	0.0936 0.1679
Price					0.3917	0.3734 0.3978	0.1139	0.0088 0.1419

Table 3. Rankings of the Egyptian cotton fibre types and net outranking flows under different scenarios.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Rank	Type	φ	Type	φ	Type	φ	Type	φ
1	Giza 87	0.6716	Giza 87	0.4386	Giza 92	0.2884	Giza 87	0.3117
2	Giza 93	0.4658	Giza 92	0.2149	Giza 87	0.1402	Giza 92	0.2291
3	Giza 92	0.2524	Giza 93	0.1285	Giza 86	−0.0094	Giza 86	0.1795
4	Giza 88	0.0816	Giza 86	0.1180	Giza 90	−0.0567	Giza 93	0.0028
5	Giza 70	−0.2233	Giza 70	−0.1553	Giza 88	−0.0977	Giza 70	−0.1361
6	Giza 86	−0.4860	Giza 90	−0.3227	Giza 93	−0.1281	Giza 90	−0.1687
7	Giza 90	−0.7620	Giza 88	−0.4221	Giza 70	−0.1367	Giza 88	−0.4183

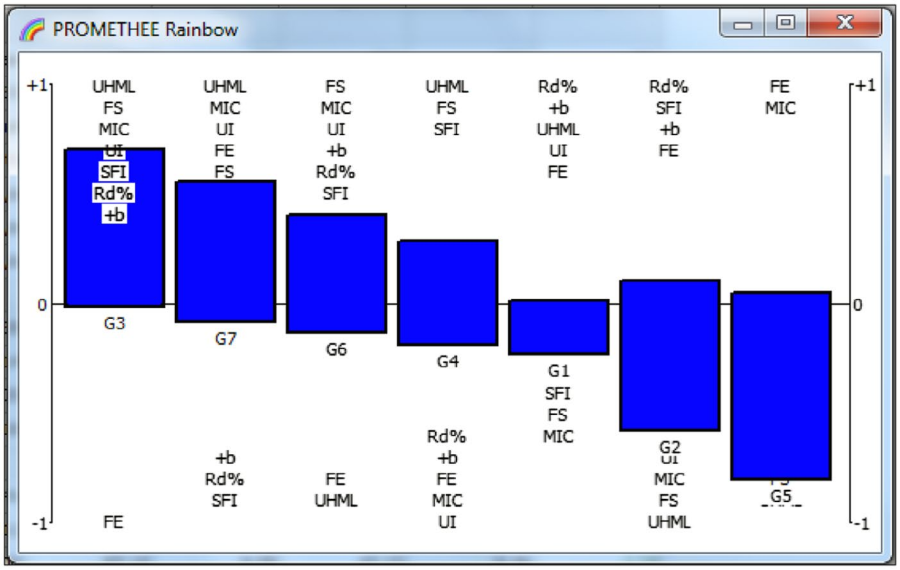
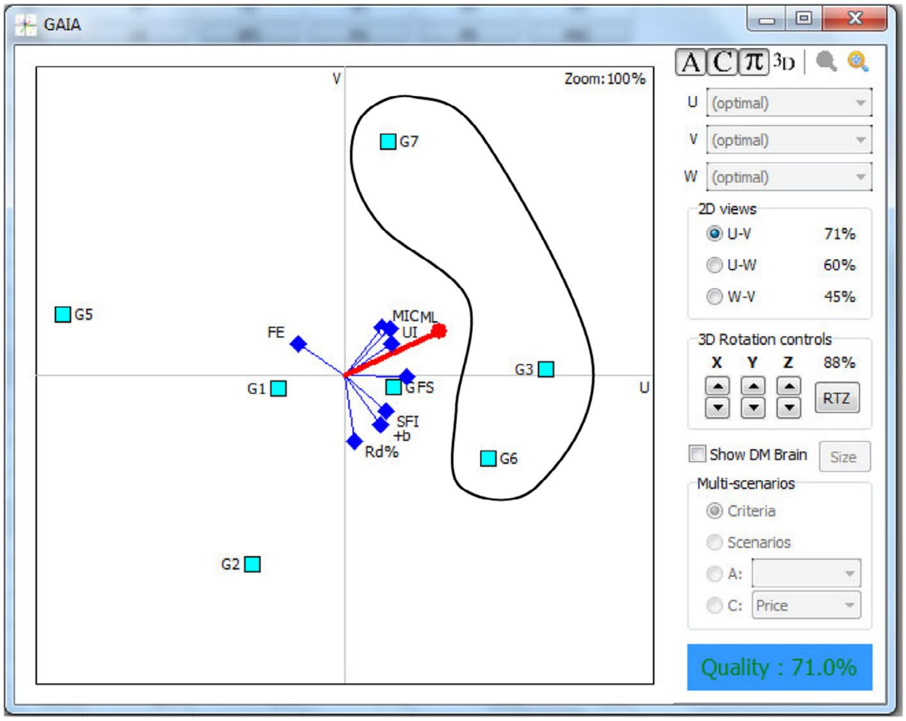


Figure 1. PROMETHEE rainbow diagram for the Egyptian cotton fibres under scenario 1.

outperforms the other competing fibre alternatives with respect to all the considered physical properties, except fibre elongation. As compared to other fibre types, it has excellent values for UHML, fibre strength and micronaire. On the other hand, Giza 90 (G_5) has only two favourable ('bonus') properties, i.e. fibre elongation and micronaire. These observations can easily be validated from the data provided in Table 1. For scenario 1, the corresponding GAIA plane is developed in Figure 2 where Giza 87 (G_3), 92 (G_6) and 93 (G_7) form a distinct cluster having almost similar property profiles. It is also noticed that Giza 86 (G_2) and 90 (G_5) are almost outliers in the GAIA plane. The decision axis is directed towards Giza 87 (G_3) proving its superiority over the other fibre alternatives. As all the cotton fibre properties, except fibre elongation, are oriented towards Giza 87, it has thus favourable values with respect to those properties. A reliability value of 71.0% indicates that this Egyptian cotton fibre selection is a moderately difficult problem to solve. Similar observations are also noticed for scenario 2.

The situation entirely changes when the additional criterion in terms of cotton fibre price is taken into consideration for the Egyptian cottons. Under scenarios 3 and 4, Giza 86, 87 and 92 occupy the top three positions in the derived ranking lists, as exhibited in Table 2, with a slight interchange between their rank orderings. It can again be propounded that the influences of subjective and objective methods of significance estimation are almost negligible on the rankings of the top three Egyptian cotton fibre types. In the GAIA plane for scenario 3, as shown in Figure 3, Giza 86 (G_2), 87 (G_3) and 92 (G_6) are in the same cluster having almost similar property profiles. The same cluster consisting of these three fibre types is also formed in the GAIA plane for scenario 4. It is quite interesting to notice that in all the four scenarios, Giza 87 belongs in the top two-listed fibres due to its excellent UHML, fibre strength, micronaire and uniformity index values.

Hence, the application of PROMETHEE II and GAIA approaches helps in identifying the most suitable Egyptian cotton fibre types to be considered for the subsequent blending process. As a perfect cotton fibre can never be available satisfying all the set objectives of the mix, it thus becomes mandatory to develop a multi-criteria optimization model based on PROMETHEE V method in order to determine the composition of different fibre types in the mix. The resulting optimal mix of the constituent cotton fibres must fulfil a given set of constraints and goals. For the purpose of developing this multi-criteria optimization model, the resulting net outranking flow values of Table 3 are treated as the coefficients of the objective function according to Equation (6). In addition, the average physical property values, as provided in Table 1, are considered here as the right-hand side constants in the constraint equations. The defined objective function and the set of constraints for scenario 1 are exhibited in Table 4. This LP problem is subsequently solved using MATLAB (R2014b) and the derived optimal solution is given in Table 5. This table also exhibits the sets of the optimal solutions for the remaining scenarios. Based on these results, it now becomes possible to



U (optimal)
V (optimal)
W (optimal)

2D views
● U-V 71%
○ U-W 60%
○ W-V 45%

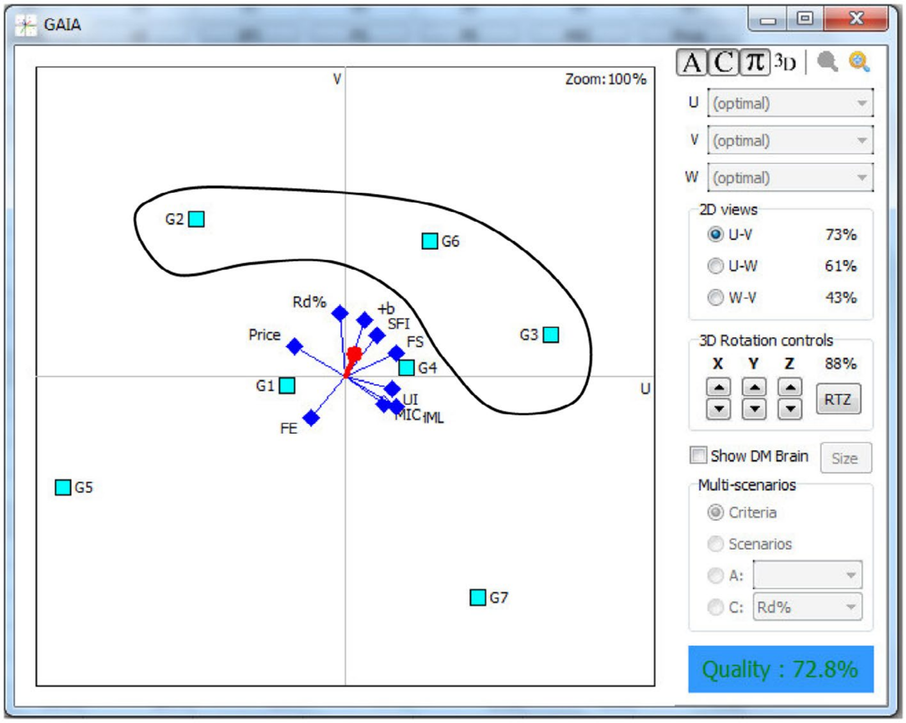
3D Rotation controls
X Y Z 88%
RTZ

☐ Show DM Brain
Size

Multi-scenarios
● Criteria
○ Scenarios
○ A:
○ C: Price

Quality : 71.0%

Figure 2. GAIA plane for the Egyptian cotton fibres under scenario 1.



U (optimal)
V (optimal)
W (optimal)

2D views
● U-V 73%
○ U-W 61%
○ W-V 43%

3D Rotation controls
X Y Z 88%
RTZ

☐ Show DM Brain
Size

Multi-scenarios
● Criteria
○ Scenarios
○ A:
○ C: Rd%

Quality : 72.8%

Figure 3. GAIA plane for the Egyptian cotton fibres under scenario 3.

establish the optimal proportions of the Egyptian cotton fibre types for subsequent blending. For scenario 1, it can be observed that Giza 87 (60.06%) and Giza 93 (30.12%) are the two main constituents in the blend, with slight addition of Giza 90 (9.82%). On the other hand, in scenario 2, the proportions of Giza 87 and Giza 90 are respectively 84.25 and 15.75% in the blend. The inclusion of Giza 90 in the final blend in both the scenarios can be validated through its excellent fibre elongation property which would be responsible to satisfy the constraint with respect to this property. Thus, the unfavourable property (fibre elongation) of Giza 87 gets compensated by Giza 90. In scenario 2, the percentage contribution of Giza 90 is more as compared to scenario 1

Table 4. Objective function and set of constraints in multi-criteria optimization model for scenario 1.

Maximize $Z = -0.2233X_1 - 0.4860X_2 + 0.6716X_3 + 0.0816X_4 - 0.7620X_5 + 0.2524X_6 + 0.4658X_7$
Subject to
$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 = 1$
$74.58X_1 + 75.80X_2 + 75.08X_3 + 66.78X_4 + 67.36X_5 + 74.63X_6 + 65.89X_7 \geq 71.44$ (reflectance)
$9.59X_1 + 9.11X_2 + 9.40X_3 + 11.85X_4 + 11.98X_5 + 8.78X_6 + 11.68X_7 \leq 10.34$ (yellowness)
$34.41X_1 + 33.11X_2 + 36.00X_3 + 35.38X_4 + 29.39X_5 + 33.91X_6 + 36.14X_7 \geq 34.05$ (UHML)
$86.45X_1 + 86.40X_2 + 87.15X_3 + 86.33X_4 + 85.11X_5 + 86.73X_6 + 87.23X_7 \geq 86.48$ (uniformity index)
$9.79X_1 + 9.62X_2 + 9.59X_3 + 9.55X_4 + 10.49X_5 + 9.77X_6 + 9.79X_7 \leq 9.80$ (short fibre index)
$46.23X_1 + 43.94X_2 + 47.23X_3 + 46.86X_4 + 33.43X_5 + 47.49X_6 + 46.35X_7 \geq 44.50$ (fibre strength)
$6.40X_1 + 6.46X_2 + 6.36X_3 + 6.15X_4 + 7.63X_5 + 6.33X_6 + 6.61X_7 \geq 6.56$ (fibre elongation)
$4.16X_1 + 4.51X_2 + 3.14X_3 + 4.15X_4 + 4.13X_5 + 3.91X_6 + 3.16X_7 \leq 3.88$ (micronaire)

Table 5. Optimal sets of solutions under different scenarios for the Egyptian cotton types.

Variety	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Giza 70	0	0	0	0
Giza 86	0	0	0.0165	0.0174
Giza 87	0.6006	0.8425	0.4862	0.4756
Giza 88	0	0	0	0
Giza 90	0.0982	0.1575	0.1754	0.1642
Giza 92	0	0	0.3219	0.3427
Giza 93	0.3012	0	0	0
Objective function value	0.4688	0.3187	0.1561	0.2022

because in scenario 2, fibre elongation has more relative importance against scenario 1. But, in both the scenarios, Giza 87 has the prime contribution in the final blend.

The entire situation changes in scenarios 3 and 4 when the economic aspect with respect to cotton fibre price is taken into account in the multi-criteria optimization model. In scenario 3, Giza 87 and 92 become the main contributors, with the inclusion of Giza 86 and 90 in the final blend. In scenario 4, Giza 87 and 92 altogether has a total share of almost 82% in the final blend, while the remaining contribution is provided by Giza 86 and 90 due to their less unit purchase prices.

These solutions indicate the fact that if the spinning industry personnel are only interested in the physical properties of the Egyptian cotton types, Giza 87 and Giza 90 would provide the optimal blending mix as they have the best combinations of majority of the beneficial and non-beneficial properties. Similarly, when the additional economic criterion is considered in this multi-criteria optimization model, Giza 87 and Giza 92 offer the maximum contributions in the optimal blend mix, with the inclusion of two other less costly fibre types (Giza 86 and 90) in order to fulfil the given constraint in terms of cotton fibre price.

4.2 Ethiopian variety

In this example, 12 cotton fibre types of the Ethiopian variety are considered and their detailed physical properties are exhibited in Table 6. This table also provides the price information of various fibre types, and the average and CV% values of all the physical properties under consideration. Similarly, the relative significances of those properties are measured subjectively and objectively using AHP and entropy methods respectively. Likewise in the first example, the first two scenarios take into account only the physical properties of the Ethiopian cotton fibre types; and in scenarios 3 and 4, an additional economic consideration with respect to fibre price is incorporated in the multi-criteria optimization model. These criteria weights, as measured subjectively and objectively under the four different scenarios, are shown in Table 7 along with their calculated stability intervals. It is worthwhile to mention here that as the considered physical properties of the Ethiopian cotton fibre types remain the same, their priority weights as estimated using AHP method are unaltered. But, due to varying values of these properties, the weights measured objectively employing entropy method are changed. Now, adopting the PROMETHEE II procedural steps, the corresponding values of the net outranking flows are computed, as provided in Table 8. It is observed that in scenarios 1 and 2, the fibre types SJ-2 (F_3) and Sille1 (Stone Vile) (F_{10}) are in the top two positions of the derived ranking list. In scenario 2, their relative positions are only interchanged. In both the cases, there

Table 6. Physical properties of the Ethiopian cotton fibre types (Tesema & Hussein, 2015).

Property									
Type	Rd%	+b	UHML	UI	SFI	FS	FE	MIC	Price (USD/kg)
DP-90 (F_1)	70.75	7.65	29.25	80.88	12.45	24.70	5.73	4.10	3.65
Cu-ok-ra (F_2)	75.40	8.78	29.13	80.20	13.13	23.48	5.83	4.30	3.62
SJ-2 (F_3)	79.10	8.38	29.50	81.83	12.08	25.88	6.08	4.05	3.70
Arba (F_4)	78.98	8.78	29.73	81.28	12.70	25.68	5.95	4.20	3.78
LaoCara (F_5)	78.25	8.60	27.58	80.55	13.15	22.25	5.60	3.63	3.55
Alber 637 (F_6)	77.25	8.38	28.05	79.48	13.38	25.33	5.88	5.10	3.60
BPA (F_7)	76.78	8.23	30.65	82.23	12.40	22.95	5.73	4.25	3.95
Cucrova 1518 (F_8)	75.50	7.75	29.61	84.45	12.55	21.70	6.03	4.13	3.72
Bulk 202 (F_9)	75.38	8.80	30.05	86.20	13.35	23.55	6.18	4.20	3.85
Sille1 (Stone Vile) (F_{10})	78.40	8.35	30.10	84.00	12.10	23.78	6.13	3.90	3.88
Estamble (F_{11})	78.53	8.78	26.58	85.05	12.35	24.50	5.93	3.73	3.50
R-36 (F_{12})	77.35	8.00	27.91	84.15	13.15	24.00	6.13	4.23	3.53
Mean	76.81	8.37	29.01	82.52	12.73	23.98	5.93	4.15	3.69
CV%	2.92	5.40	4.11	2.64	4.11	5.36	4.83	8.99	3.95

Table 7. Weights and their stability intervals for the Ethiopian cotton fibre types.

Property	Scenario 1 (Subjective weight)		Scenario 2 (Objective weight)		Scenario 3 (Subjective weight)		Scenario 4 (Objective weight)	
Rd%	0.0302	0.0300 0.0823	0.0604	0 0.0757	0.0228	0.0042 0.0433	0.0545	0.0453 0.0749
+b	0.0302	0 0.0305	0.2629	0.2499 0.3831	0.0228	0 0.0358	0.2373	0.2245 0.2447
UHML	0.3256	0.3228 0.3256	0.0871	0.0784 0.1108	0.1825	0.1781 0.1870	0.0786	0.0609 0.0932
UI	0.0951	0.0878 0.0953	0.1489	0.0784 0.1655	0.0612	0.0587 0.0704	0.1344	0.1235 0.1973
SFI	0.0734	0.0729 0.0996	0.1735	0.1549 0.2080	0.0493	0.0312 0.0555	0.1566	0.1182 0.1755
FS	0.2625	0.2624 0.2654	0.1065	0.0688 0.1248	0.1531	0.1485 0.1635	0.0961	0.0839 0.1129
FE	0.0346	0.0134 0.0349	0.1014	0.0737 0.1124	0.0257	0.0224 0.0308	0.0915	0.0683 0.1766
MIC	0.1487	0.1420 0.1491	0.0591	0.0352 0.0712	0.0910	0.0840 0.0945	0.0534	0.0251 0.0698
Price					0.3917	0.3879 0.3949	0.0974	0.0852 0.1142

Table 8. Rankings of the Ethiopian fibre types and their net outranking flows under different scenarios.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
Rank	Type	φ	Type	φ	Type	φ	Type	φ
1	F_3	0.4702	F_{10}	0.4547	F_{11}	0.4045	F_3	0.3592
2	F_{10}	0.4701	F_3	0.4078	F_3	0.2536	F_{10}	0.3507
3	F_4	0.3117	F_8	0.2485	F_{12}	0.2131	F_{12}	0.2124
4	F_9	0.1233	F_1	0.1650	F_1	0.0804	F_8	0.1978
5	F_7	0.0862	F_{12}	0.1470	F_4	−0.0011	F_{11}	0.1737
6	F_1	0.0819	F_7	0.1034	F_6	−0.0181	F_1	0.1579
7	F_{11}	−0.0110	F_{11}	0.0845	F_5	−0.0259	F_7	−0.0041
8	F_8	−0.0726	F_4	−0.0491	F_{10}	−0.0349	F_4	−0.0886
9	F_{12}	−0.2005	F_9	−0.1884	F_8	−0.1431	F_9	−0.2320
10	F_6	−0.3102	F_6	−0.3865	F_9	−0.1863	F_6	−0.3047
11	F_5	−0.4675	F_5	−0.4454	F_2	−0.1912	F_5	−0.3399
12	F_2	−0.4816	F_2	−0.5416	F_7	−0.3511	F_2	−0.4623

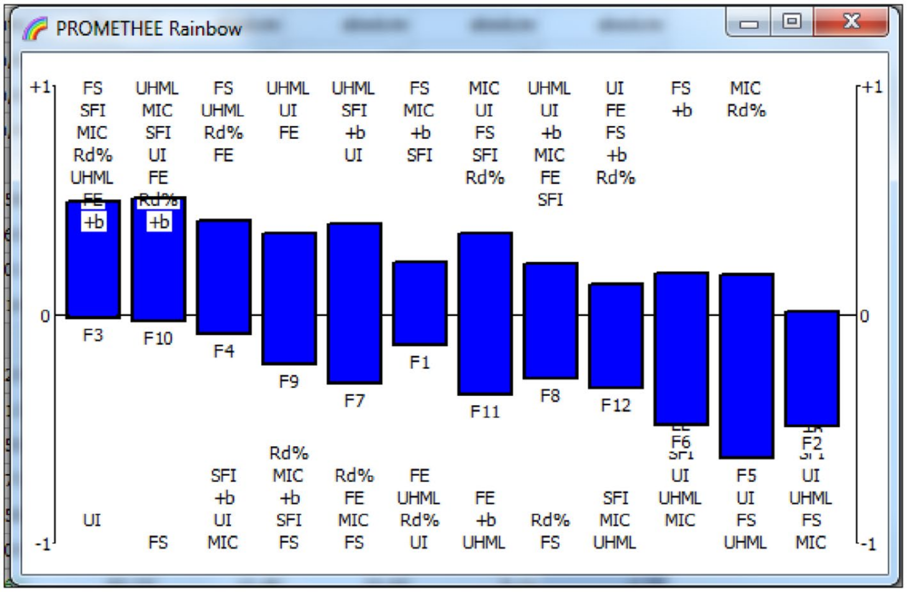
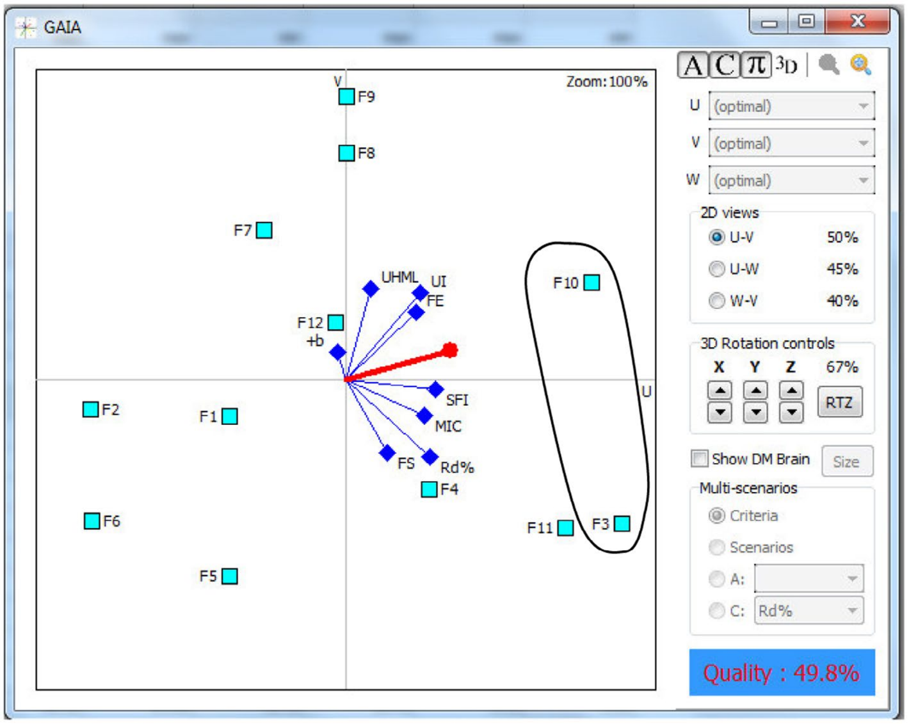


Figure 4. PROMETHEE rainbow for the Ethiopian cotton fibres under scenario 1.

are marginal differences in their calculated net outranking flow values. For scenarios 1 and 2, cotton fibre-type Cu-ok-ra (F_2) occupies the last position in the ranking list. Thus, the positions of the best two and the worst cotton fibre types in scenario 2 are almost exactly the same as those in scenario 1. In scenario 3, fibre-type SJ-2 (F_3) is in the second position in the ranking list and the position of Cu-ok-ra (F_2) is just before the worst-ranked fibre alternative. In scenario 3, Estamble (F_{11}) is identified to be the best performing cotton fibre type due to its least procurement cost as compared to others. In scenario 3, as more importance



U (optimal)
V (optimal)
W (optimal)

2D views
● U-V 50%
○ U-W 45%
○ W-V 40%

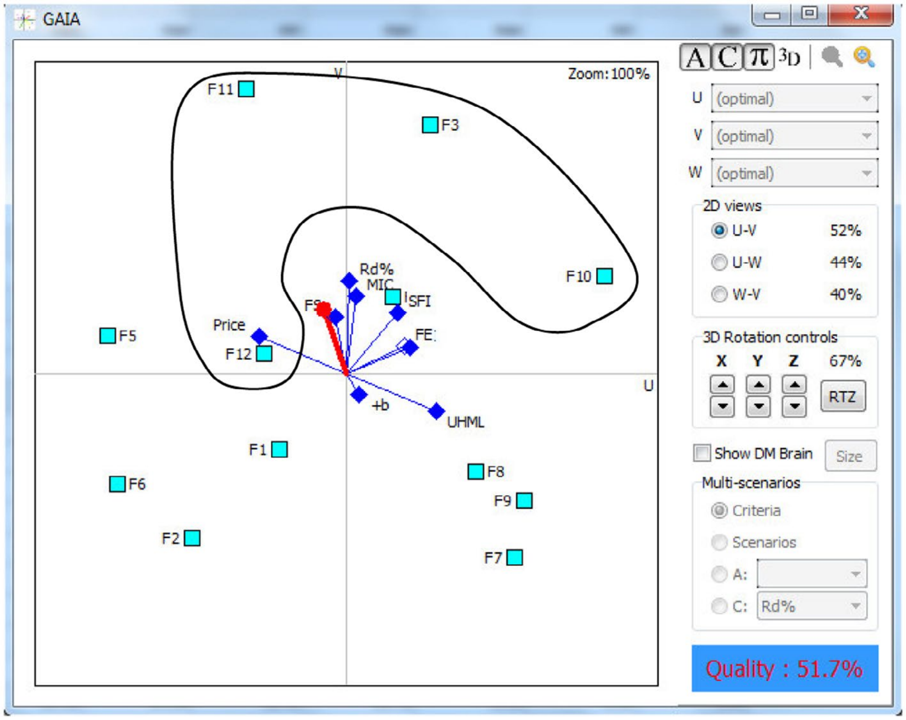
3D Rotation controls
X Y Z 67%
RTZ

☐ Show DM Brain Size

Multi-scenarios
● Criteria
○ Scenarios
○ A:
○ C: Rd%

Quality : 49.8%

Figure 5. GAIA plane for the Ethiopian cotton fibres under scenario 1.



U (optimal)
V (optimal)
W (optimal)

2D views
● U-V 52%
○ U-W 44%
○ W-V 40%

3D Rotation controls
X Y Z 67%
RTZ

☐ Show DM Brain Size

Multi-scenarios
● Criteria
○ Scenarios
○ A:
○ C: Rd%

Quality : 51.7%

Figure 6. GAIA plane for the Ethiopian cotton fibres under scenario 3.

is assigned to cotton fibre price criterion, the top rank is thus occupied by a fibre having the minimum purchase price. In scenario 4, as the fibre price criterion has not so much importance, the top order ranking pattern is observed to be the same as that for scenario 1.

From the PROMETHEE rainbow diagram for scenario 1, as depicted in Figure 4, it is noticed that the top ranked fibre alternative (SJ-2) is the excellent performer with respect to all the physical properties, except uniformity index. On the other hand, the second ranked Ethiopian fibre (Sille1) lags behind only with respect to fibre strength property, although its remaining properties are quite favourable. Interestingly, the last ranked Ethiopian cotton fibre (Cu-ok-ra) has no properties in its favour. In the GAIA plane for scenario 1, as exhibited in Figure 5, developed

Table 9. Optimal set of solutions under different scenarios for the Ethiopian cottons.

Type	Scenario 1	Scenario 2	Scenario 3	Scenario 4
F_1	0	0	0	0
F_2	0	0	0	0
F_3	0.6667	0.0952	0.7403	0.7232
F_4	0	0	0	0
F_5	0	0	0	0
F_6	0	0	0	0
F_7	0	0	0	0
F_8	0	0	0	0
F_9	0	0	0	0
F_{10}	0.3333	0.9048	0.0266	0.1120
F_{11}	0	0	0.1018	0.0718
F_{12}	0	0	0.1313	0.0930
Objective function value	0.4702	0.4502	0.2560	0.3313

employing the PROMETHEE-GAIA software, the direction of the decision axis clearly indicates the superiority of the Ethiopian cotton fibres SJ-2 (F_3) and Sille1 (Stone Vile) (F_{10}) over their competing alternatives. Similarly, from the GAIA plane for scenario 3, as portrayed in Figure 6, the superiority of Estamble (F_{11}) is well noticed based on the direction of the decision axis towards it.

Now, based on Equation (6) and following the steps as adopted in the earlier example, the corresponding objective functions and constraints are also developed here for the four different scenarios. The optimal solutions with respect to the proportions of the constituent Ethiopian fibre types in the final blend are provided in Table 9. For the first two scenarios, the types of the component fibres (F_3 and F_{10}) in the blend remain the same, only there is a remarkable change in their proportionate amounts. It can be noticed here that the objective function for this optimization problem is developed based on the net outranking flow values of the considered cotton fibres which needs to be maximized. In scenario 2, the net outranking flow of F_{10} is higher than that of F_3 which is responsible to have a greater contribution of F_{10} in the final mix. Thus, it can be concluded that the methods of determining the relative significance of various fibre properties have insignificant effect on the blend composition. The proportionate amounts of different component fibres in the blend solely depend on their calculated net outranking flow which is an aggregated measure of all the considered fibre properties. For scenarios 3 and 4, the blend compositions are observed as expected, with the inclusion of Estamble (F_{11}) and R-36 (F_{12}) in the final mix due to their least purchase prices. This multi-criteria optimization model, integrating PROMETHEE II and V, and GAIA methods is thus observed to have immense importance in ranking the considered cotton fibre alternatives from the best to the worst, identifying the top ranked fibre alternatives, and identifying the constituent fibres in the blend mix along with their proportionate amounts.

In order to study how the requirement for a particular physical property of cotton fibre is fulfilled while varying the compositions of the constituent fibres in the blend, a sensitivity analysis is performed, as shown in Figure 7. In scenario 4, it is observed that reflectance is the most important property (priority weight of 0.2373) for the Ethiopian cotton fibres when weights are measured objectively and it is required to attain its value greater than 8.37 (average reflectance value). The SJ-2 having a reflectance value of 8.38 would obviously be the main contributor in the blend. When lower values of reflectance are required, R-36 (reflectance value of 8.00) would be in the mix. On the other hand, for achieving higher reflectance values, R-36 would be replaced by Sille1 (Stone Vile) and Estamble cotton types. For still higher values of reflectance, the proportionate amount of Estamble (reflectance value of 8.78) would go on increasing in the blend composition. Similarly, in Figure 8, the variations in the compositions of the Ethiopian cotton fibre types for changing values of UHML (having the maximum importance of 0.3917 in scenario 3) are exhibited. In this case, the target UHML is set to be greater than 29.01 mm (average UHML value) which can almost be solely satisfied by SJ-2 having an UHML of 29.50 mm. For lower values of UHML, the contributions of R-36 (UHML = 27.91 mm) and Estamble (UHML = 26.58 mm) are observed to be significant. On the other hand, for higher values

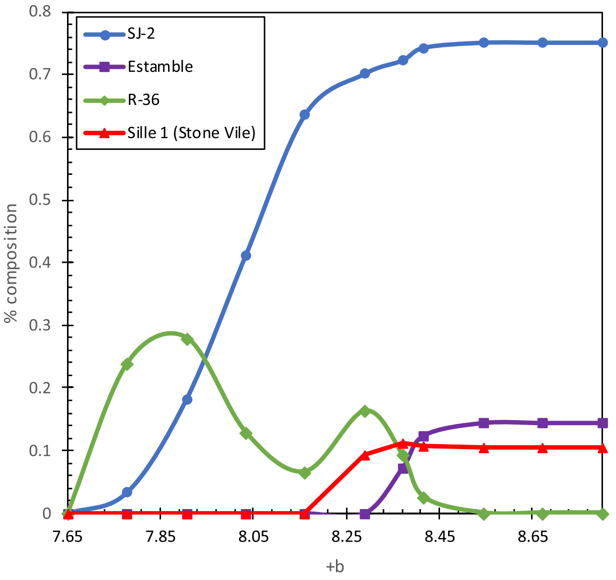


Figure 7. Compositions of the Ethiopian cotton fibre types for varying values of reflectance.

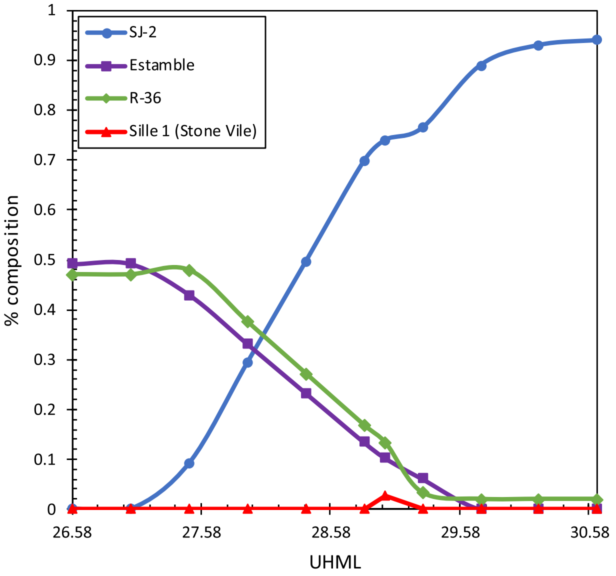


Figure 8. Compositions of the Ethiopian cotton fibre types for varying values of UHML.

of UHML, the proportionate amount of SJ-2 in the final blend goes on steadily increasing with the decrement in the percentage contributions of the other fibre types.

5. Conclusions

In this paper, a multi-criteria optimization model is developed while combining PROMETHEE II and V, and GAIA methods. The application of PROMTHEE II method provides a complete ranking order of the considered cotton fibre types, while identifying the best and the worst performing candidate fibres. On the other hand, the developed GAIA plane indicates the relative positions of the fibre alternatives with respect to their 'bonus' and 'penal' properties. It also helps in indicating the strengths and weaknesses of each cotton fibre type. The net outranking flows as calculated in PROMETHEE II method and the average fibre property values are finally augmented in the optimization model of PROMETHEE V approach. From the solutions of the developed multi-criteria optimization models for both the Egyptian and Ethiopian cotton fibre types, it can be clearly noticed that the addition of the cotton fibre price criterion in the model has significant effect in the final blend composition with the inclusion of the least priced fibre type in the mix. The subjective and objective approaches for estimating the relative priority weights of various fibre properties have almost insignificant effect on the blend composition. Sensitivity analysis studies are also performed to investigate the variations of the proportionate amounts of the constituent fibres in the blend for changing values of some of the important physical properties of the considered cotton fibres. As this model takes into consideration all the fibre properties, including their price (net outranking flow is an aggregated measure of all the physical properties under consideration), it can be expected that the model would always provide a more realistic and accurate blend composition for the considered fibre varieties. The application of this model can also be extended to other natural fibres where the blend compositions are seriously affected by their highly variable heterogeneous physical properties.

Disclosure statement

No potential conflict of interest was reported by the authors.

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