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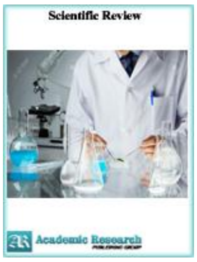

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Choosing the Appropriate Mordant via Multi-criteria Decision Making Methods in Natural Dyeing with Tea Extract

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Abstract: This study examined the usability of natural dye obtained from tea for dyeing woolly Bayburt Ehram, a traditional weaving, and the effects of natural mordants and chemical mordants on dyeing numerically. Bayburt Ehram is woven from 100% wool fibre. In this study Bayburt Ehram woven of 100% wool fibre was dyed with 15 different concentrations of 3 different mordant substances. Light fastness and washing fastness tests of the samples were done and colour differences and colour productivity calculated using CIE L*a*b colour space system were compared. VIKOR method was used for the optimization of dyeing parameters and step-by-step solution was shown. This is one of the multi-criteria decision making methods, and aims to rank and choose the best among many alternatives and enables the decision maker to take a decision using agreeable solutions and acceptable advantage and stability for a multi-criteria problem. It is an alternative and effective method to use for problems. Then ranking was done using GREY RELATIONAL ANALYSIS (GRA) and TOPSIS method and the results were compared using Spearman rank order correlation test and the most effective method was chosen. The experimental results show that using potassium aluminium sulphate mordant gives the best results in terms of colour difference and colour yield for dyeing the woolly fabric with tea.
Keywords: Multi-criteria decision making; Natural dyeing; Spearman rank order correlation; Choosing mordant.

1. Introduction

Anatolia is home to a lot of civilizations and Turkish fabric, rug and carpet weaving has a rich weaving culture as a combination and continuation of these cultures. Many cities, towns, and villages were known to be weaving centres in the past and natural colorants were known to be used to dye these weavings. Known as madders colloquially, dyes are derived not only from plant roots but also from vines, pests, and minerals [1].

Many natural dyes either fade or do not acquire a colour so long as they are not processed with mordants enabling the colours to bind on fibres or fabrics. Mordants are used to yield both colour fastness and to derive various colour shades of the same colorant [2].

The consumer expects the colour not to fade as washed or used. While the formula is being specified, the appropriate mordant and correct amount of mordant should be identified.

2. Multi-criteria Decision-Making

Multi-criteria decision-making methods are implemented in various fields to make decisions by choosing, ranking and classifying. Various methods using qualitative and quantitative data for calculations by considering different performance criteria and their loads are made use of. Among these methods are ELECTRE, TOPSIS, Fuzzy TOPSIS, GREY RELATIONAL ANALYSIS, Ahp, Fuzzy Ahp, PROMETHEE, and VIKOR etc. GREY RELATIONAL ANALYSIS, TOPSIS, and VIKOR methods are used commonly in the literature to make a choice and to rank among many alternatives by taking multi-criteria into consideration [3].

MCDM has a structure that figures out a lot of criteria and multi-alternatives simultaneously by bringing them together. In MCDM method certain steps are to be followed and the aim for MCDM method is that the decision-maker can make an advantageous choice among many alternatives under close or confounding criteria. The steps are as follows [4].

a) The related criterion and alternative is identified.
b) Proportional importance degrees of the criteria are determined
c) Each alternative is assessed by all criteria and the alternatives are ranked and chosen.

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2.1. VIKOR Method

VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method was suggested by Opricovic in 1998 to solve multi-criteria decision problems that are conflicting [5] In this method, multi-criteria rank index for alternatives is created and the decision closest to the ideal solution is made under certain conditions. By comparing the closeness to the ideal alternative values, the compromised rank is found [6]. This compromise solution will be accepted by the decision maker since it will provide maximum group utility for the majority and minimum regret for the opponents [7].

The VIKOR procedure has the following steps:

Step 1*.Determining the best* (f_i^*) *and the worst* (f_i^-) *values:*

The first step of VIKOR method is to determine the best (f_i^*) and the worst (f_i^-) values. For benefit the highest (max) value of the criteria and for cost the lowest (min) value is chosen. In the formulas below i shows comparison criteria (i=1,2,3,...,n) and j shows alternatives (j=1,2,3,...,m). The best $(f_i^*)$and the worst (f_i^-) values are determined for each criterion with the help of (Equation 1) and (Equation 2)

$f_i^* \max_j f_{ij}$, $f_i^- \min_j f_{ij}$, if the i-th function is benefit; (Equation1)

$f_i^* \min_j f_{ij}$, $f_i^- \max_j f_{ij}$, if the i-th function is cost, (Equation 2)

Step 2*.Computing the values Sj and Rj*

After the best (f_i^*) and the worst (f_i^-) values are determined for each criterion, Sj and Rj values are computed for each alternative. (Equation 3) and (Equation 4) Sj shows average group and Rj shows the best group value.

$$S_j = \sum_{i=1}^{n} \frac{w_i(f_i^* - f_{ij})}{f_i^* - f_i^-} \quad \text{(Equation 3)}$$

$$R_j = max\left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)}\right] \quad \text{(Equation 4)}$$

W_i value in (Equation 3) and (Equation 4) shows the weights of each criterion. In our study weight of each criterion is accepted equal.

Step 3*.Computing the values Qj: Qj values determined according to evaluation criteria for each alternative with the help of (Equation 5) show maximum group benefit.*

$$Q_j = \frac{v(S_j - S^*)}{(S^- - S^*)} + \frac{(1-v)(R_j - R^*)}{(R^- - R^*)} \quad \text{(Equation 5)}$$

S* : Minimum Sj value R*: Minimum Rj value,

S- : Maximum Sj value R- : Maximum Rj value

v Value is weight value for the strategy of maximum group utility whereas (1-v) Value is the weight of the individual regret of the opposing decision makers.

In VIKOR method v>0,5 represents majority preference for maximum group benefit, v=0,5 shows consensus (compromise) and v<0,5 shows veto and the v Value is determined by group decision. v=0,5 is the accepted value in our study considering compromise and the literature [3].

Step 4*.Ranking Sj, Rj and Qj Values:*

The alternatives are ranked, sorting by the values Sj, Rj and Qj, from the minimum value.

Step 5*.Determining the Acceptable Advantage (C1) and Acceptable Stability (C2) Sets:*

Acceptable advantage (C1) and acceptable stability (C2) sets are determined for decision makers according to the rank of Sj, Rj, and Qj values. For this aim:

1. Acceptable Advantage in Decision Making -C_1

In order for any alternative to be in C1 set (Acceptable Advantage), the condition shown in (Equation 6) should be fulfilled.

$$Q(A_2) - Q(A_1) \geq DQ \quad \text{(Equation 6) is}$$

computed with $DQ = \frac{1}{(m-1)}$

The smaller the difference between the best and the second best alternative is, the more advantageous to choose the best alternative is

2. Acceptable Stability in Decision Making -C_2

The alternative $A^{(1)}$ must also be the best ranked by S or/and R, which means that the compromise solution in decision making has acceptable stability. Unless one of the conditions is satisfied, a set of compromise solutions is proposed: If only the condition C2 is not satisfied, alternatives $A^{(1)}$ and $A^{(2)}$) do not pair off and R series C3 is implemented.

3. Set of Compromise Solutions -C3

If the condition C1 is not satisfied, alternatives $A^{(1)}$, $A^{(2)}$,..., $A^{(M)}$ make the set of compromise solutions that enables the $Q(A^{(M)})$-$Q(A^{(1)})$<DQ relation [7].

2.2. Spearman Test

Spearman test is a statistical series method that measures the rank relationship of two different data sets and computation equations are shown below.

In equations d^n shows the difference between each element of the two different data sets, N shows the number of data, ρ shows the measure of consistency, and Z describes test statistics. ρ value in this test shows positive and negative consistency for ±1,00 value. To provide an acceptable consistency between the two ranks, ρ is expected to be higher than ±0,50 value. On the other hand, is an acceptable Z value is bigger than $Z\alpha$ Table value ($Z_{0.05}$ =1,645) for the selected α=0,05 value, rank results of the two data sets will be accepted to be consisted. Otherwise they will be rejected [8].

$$d^n = x^n - y^n \text{ , } n=1,.....,N \qquad \text{(Equation 7)}$$

$$\rho = 1 - \left\{6.\left[\frac{\sum_{n=1}^{N}(d^n)^2}{N.(N^2-1)}\right]\right\} \qquad \text{(Equation 8)}$$

$$Z = \rho.\sqrt{(N-1)} \qquad \text{(Equation 9)}$$

3. Material and Method

3.1. Material

Plain weave Bayburt Ehram woven of 100% wool fibre was used in this study. Fabric weight was 290,2 g/m^2, weft density was 12,4 tel/cm and warp density was 11,4 tel/cm. Yarn count was Nm 8,5~9. Potassium aluminium sulphate was used as metallic mordant and, Quercus Aegilops extract and citric acid were used as bio-mordant, and tea extract was used as natural mordant.

3.2. Equipments

Gyrowash Washer Tester
Light fastness test device (Solarbox 1500E)
Datacolour Spectra Flash 600

3.3. Method

3.3.1. Pretreatment

The woolly fabric was pretreated with 1g/L soap+2g/L soda+1g/L wetter in the flotte at 55^{o}C and at a rate of 10,5 Ph, 1/50 flotation.

3.3.2. Mordanting

100 g Quercus Aegilops was filtered and cooled after boiling for 1 hour in 100 mL distilled water. The mordanting flotte prepared at 1/100 ratio was prepared to include Quercus Aegilops at %3, 5%, 10%, 15% and 20% (o.w.f.) concentration. The materials were processed at boiling temperature for 1 hour, kept in flotte for 24 hours and dried. The citric acid mordant was prepared at 2%, 4%, 6%, 8%, 10% (o.w.f.) concentration and %3, 5%, 10%, 15%, and 20% (o.w.f.) concentration and potassium aluminium sulphate mordant was prepared at %3, %5, %10, %15, %20 (o.w.f.) concentration. The material was processed at boiling temperature for 1 hour in flotte of which flotte rate was 1/100, kept in this flotte for 24 hours and dried.

3.3.3. Preparation of Dye Extract and Dye Flotte from Tea

1000 g of tea was filtered and cooled after boiling for 1 hour in 12550 mL distilled water. The mordanted samples were dyed with the dye extract prepared at a 1/100 flotte rate and 12, 55 ml for 1 g sample at100^{o}C for 60 minutes. It was kept in flotte for 24 hours and dried.

3.3.4. Dyeing Process

Dyeing was started at 30°C. Flotte was elevated to boiling temperature in 20 minutes and dyed for 1 hour at this temperature. The dyed samples were kept in flotte for 24 hours and then wash and cold wash processes were carried out.

3.3.5. Colour Measurements

Colour measurements of the dyed samples were done via Datacolour Spectra Flash 600 plus reflectance spectrophotometer using Datamaster software according to CIELab system. Colour measurements were done using 10° observer and D65 light source [9]. Equation 10 was used to calculate the colour values in accordance with CIELab system.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \text{(Equation 10)}$$

In the formula above, L* shows lightness-darkness value, a* shows redness-greenness value, and b* shows yellowness-blueness value.

K/S Values: Colours of the dyed samples were evaluated via colouring power (K/S) calculated using Kubelka-

Munk equation (Formula 2)

$$K/S = \frac{(1-R)^2}{2R} \qquad \text{(Equation 11)}$$

R: reflectance value of the fibre in wavelength in the maximum absorption
K: absorption co-efficient
S: scattering co-efficient [9].

3.3.6. Wash Fastness and Lightfastness

Wash fastness of the test samples was done by ISO 105-C06 [10] standard in Fastness to washing test machine (Gyrowash / James H. Heal Co. Ltd.) and assessment was done by ISO A05 [11] standard using reflectance spectrophotometer. Light fastness of the samples was assessed by TS 1008 EN ISO 105-B02 [12] in light fastness test device (James H. Heal) and total colour difference between the untested sample and test samples (ΔE*) was evaluated in spectrophotometer.

4. Findings and Evaluation

Total colour differences of the samples dyed with tea extract (ΔE*), K/S values and wash fastness (colour change and staining) and light fastness values valued with spectrophotometer are given in Table 1. ΔE : Colour difference compared to the one without mordant ΔE Y: Wash fastness (Colour change)=A ΔE 1: Wash fastness(Staining) Wool=B	ΔE 2: Fastness to washing (Staining) Polyacrylonitrile=C ΔE 3: Fastness to washing (Staining) Polyester=D ΔE 4: Fastness to washing (Staining) Polyamide=E ΔE 5: Fastness to washing (Staining) Cotton=F ΔE 6: Fastness to washing (Staining) Acetate=G ΔE I: Light fastness=H K/S: Colour yield (Kubelka-Munk)(Absorption Co-efficients / Scattering Co-efficients)=I	1-A: %2 $C_6H_8O_7$ 1-B: %4 $C_6H_8O_7$ 1-C: %6 $C_6H_8O_7$ 1-D: %8 $C_6H_8O_7$ 1-E: %10 $C_6H_8O_7$ 2-A: %3 $KAl(SO_4)_2.12\ H_2O$ 2-B: %5 $KAl(SO_4)_2.12\ H_2O$ 2-C: %10 $KAl(SO_4)_2.12\ H_2O$ 2-D: %15 $KAl(SO_4)_2.12\ H_2O$ 2-E: %20 $KAl(SO_4)_2.12\ H_2O$ 3-A: %3 Quercus Aegilops 3-B: %5 Quercus Aegilops 3-C: %10 Quercus Aegilops 3-D: %15 Quercus Aegilops 3-E: %20 Quercus Aegilops

Table-1. Colour Difference and Colour Yield Experiment Result Values of Bayburt Ehram (Wool) Dyed with Tea

Reference	**Min**	**Min**	**Min**	**Min**	**Min**	**Min**	**Min**	**Min**	**Max**
KOD	ΔE Y	ΔE 1	ΔE 2	ΔE 3	ΔE 4	ΔE 5	ΔE 6	ΔE I	K/S
1-A	2,016	2,2	1,256	0,816	1,221	2,759	4,661	8,889	18,81
1-B	6,669	1,533	1,079	0,981	1,458	0,592	3,917	10,875	21,07
1-C	1,214	2,264	0,983	1,217	1,009	0,987	4,791	4,63	22,92
1-D	8,985	1,941	1,3	1,634	1,291	0,868	5,06	6,278	18,64
1-E	4,171	2,493	1,252	1,953	1,838	1,394	4,998	1,813	18,35
2-A	1,765	1,471	1,526	0,563	0,807	1,038	3,027	7,611	9,55
2-B	5,779	1,464	1,666	0,821	1,107	1,793	4,242	1,775	11,74
2-C	1,416	1,45	1,602	0,692	1,506	1,935	4,791	9,943	19,39
2-D	4,477	1,473	0,552	0,21	0,31	0,448	3,19	9,5	13,57
2-E	6,753	2,387	0,48	0,267	0,506	0,543	4,13	8,793	9,98
3-A	1,443	1,739	0,837	1,011	1,061	0,397	3,667	5,365	10,87
3-B	2,525	1,846	0,598	0,702	0,979	0,356	4,084	6,912	14,45
3-C	3,379	2,272	0,971	1,326	1,43	0,845	4,276	10,372	11,28
3-D	7,577	1,981	0,511	1,367	0,955	0,431	3,569	9,707	17,71
3-E	2,64	2,676	0,553	0,764	0,94	1,041	3,945	5,597	13,39
Unmordant	2,979	2,38	1,118	1,753	1,863	0,96	4,223	7,126	11,46
MAX	8,985	2,676	1,666	1,953	1,838	2,759	5,060	10,875	22,92
MIN	1,214	1,450	0,480	0,210	0,310	0,356	3,027	1,775	9,55

4.1. Steps of VIKOR are as follows

The results of VIKOR method which was used to compare the alternatives to choose mordant in natural dyeing with tea extract are given in Table 2 and Table 4.

Steps of VIKOR method are as follows:

Step1: *Finding the best* (f_i^*) *and the worst* (f_i^-) *values: The best and the worst values of the criteria are determined (depending on maximum and minimum values)*

$$f_i^* = \{1.214,\ 1.450,\ 0.480,\ 0.210,\ 0.310,\ 0.356,\ 3.027,\ 1.775,\ 22.92\}$$

$$f_i^- = \{8.985,\ 2.676,\ 1.666,\ 1.953,\ 1.838,\ 2.759,\ 5.060,\ 10.875,\ 9.55\}$$

***Step2**: Computing Sj and Rj Values: Equation 3 and Equation 4 are used.*

Table-2. S_j and R_j Computation Table by VIKOR Method

	$\frac{f_i^* - f_{ij}}{f_i^* - f_i^-}$									$S_j = \sum_{i=1}^{n} \frac{w_i(f_i^* - }{f_i^* - f}$
CODE	A	B	C	D	E	F	G	H	I	Sj
1-A	0,011	0,080	0,070	0,039	0,066	0,178	0,089	0,087	0,034	0,654
1-B	0,078	0,009	0,053	0,049	0,083	0,021	0,049	0,111	0,015	0,467
1-C	0,000	0,087	0,043	0,064	0,051	0,049	0,096	0,035	0,000	0,425
1-D	0,111	0,052	0,075	0,091	0,071	0,041	0,111	0,055	0,036	0,642
1-E	0,042	0,111	0,070	0,111	0,111	0,079	0,108	0,000	0,038	0,670
2-A	0,008	0,002	0,097	0,023	0,036	0,053	0,000	0,071	0,111	0,401
2-B	0,065	0,001	0,111	0,039	0,058	0,108	0,066	0,000	0,093	0,541
2-C	0,003	0,000	0,105	0,031	0,087	0,118	0,096	0,100	0,029	0,568
2-D	0,047	0,002	0,000	0,000	0,000	0,010	0,009	0,094	0,078	0,240
2-E	0,079	0,100	-0,007	0,004	0,014	0,017	0,060	0,086	0,108	0,460
3-A	0,003	0,031	0,028	0,051	0,055	0,006	0,035	0,044	0,100	0,353
3-B	0,019	0,042	0,005	0,031	0,049	0,003	0,058	0,063	0,070	0,339
3-C	0,031	0,088	0,042	0,071	0,081	0,039	0,068	0,105	0,097	0,621
3-D	0,091	0,057	-0,004	0,074	0,047	0,009	0,030	0,097	0,043	0,442
3-E	0,020	0,131	0,000	0,035	0,046	0,053	0,050	0,047	0,079	0,461
Unmordant	0,025	0,099	0,056	0,098	0,113	0,047	0,065	0,065	0,095	0,665

$$S_j = \sum_{i=1}^{n} \frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)} = \frac{1.214 - 2.016}{1.214 - 8.985} + \frac{1.45 - 2.2}{1.45 - 2.493} + \frac{0.552 - 1.256}{0.552 - 1.666} + \frac{0.21 - 0.816}{0.21 - 1.953}$$
$$+ \frac{0.31 - 1.221}{0.31 - 1.838} + \frac{0.448 - 2.759}{0.448 - 2.759} + \frac{3.027 - 4.661}{3.027 - 5.06} + \frac{1.775 - 8.889}{1.775 - 10.875} + \frac{22.92 - 18.81}{22.92 - 9.55} = 0.65486$$
$$R_j = max\left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)}\right] = 0{,}17808$$

Table-3. Results of S^*, R^*, S^-, R^- values by VIKOR method

Min	**Min**	**Maks**	**Maks**	
S*	**R***	**S⁻**	**R⁻**	***v***
0,24007	0,07038	0,67042	0,17808	0,5

***Step 3**.Computing the values Qj*

$$Q_j = \frac{v(S_j - S^*)}{(S^- - S^*)} + \frac{(1-v)(R_j - R^*)}{(R^- - R^*)} = \frac{0{,}5(0{,}654 - 0{,}240)}{(0{,}670 - 0{,}240)} + \frac{(1 - 0{,}5)(0{,}178 - 0{,}070)}{0{,}178 - 0{,}070} = 0{,}981$$

***Step 4**.Ranking Sj, Rj and Qj Values*

Table-4. Rank of S, R and Q values by VIKOR method

	$S_j = \sum_{i=1}^{n} \frac{w_i(f_i^* - f_{ij})}{f_i^* - f_i^-}$		$R_j = max\left[\frac{w_i(f_i^* - f_{ij})}{(f_i^* - f_i^-)}\right]$		$Q_j = \frac{v(S_j - S^*)}{(S^- - S^*)} + \frac{(1-v)(R_j - R^*)}{(R^- - R^*)}$	
	Sj	Sort	Rj	Sort	Qj	Sort
1-A	0,65486	14	0,17808	16	0,98192	16
1-B	0,46766	9	0,11111	11	0,45349	8
1-C	0,42522	5	0,09641	3	0,33592	4
1-D	0,64237	13	0,11111	11	0,65647	13
1-E	0,67042	16	0,11111	12	0,68906	14
2-A	0,40121	4	0,11111	11	0,37628	6
2-B	0,54193	10	0,11111	11	0,53978	10
2-C	0,56895	11	0,11816	14	0,60392	11
2-D	0,24007	1	0,09432	2	0,11111	1
2-E	0,46017	7	0,10754	7	0,42819	7

3-A	0,35344	3	0,10014	5	0,26984	3
3-B	0,33976	2	0,07039	1	0,11582	2
3-C	0,62177	12	0,10497	6	0,60402	12
3-D	0,44268	6	0,09685	4	0,35825	5
3-E	0,46142	8	0,13061	15	0,53674	9
Unmordant	0,66526	15	0,11293	13	0,69150	15

***Step** 5.Determining the Acceptable Advantage (C1) and Acceptable Stability (C2) Sets:*

1. Acceptable advantage in decision making -C_1

For acceptable stability group, DQ Value in (Equation 6) was computed as 0, 0666 for m=16 alternative (1/(16-1)) and therefore Condition 1 is void.

2. Acceptable stability in decision making -C_2

For Condition 2, 2-D option with the best Q value should obtain the best value in at least one of Sj and Rj values. When this condition is taken into account, it is possible to say that Sj=Qj value obtained after performance evaluation has the best performance. In this case, it is concluded that compromise solution bears acceptable stability in decision making.

Table-5. VIKOR, GREY RELATIONAL, and TOPSIS Methods' Rank for Choosing Mordant in Natural Dyeing with Tea Extract

	GREY RELATIONAL ANALYSIS		**VİKOR**		**TOPSİS**	
CODE	**GREY ANALYSIS**	**Sort**	**VİKOR Qj values**		**TOPSİS Ci values**	
1-A	0,65379	12	0,98192	16	0,44396	15
1-B	0,71571	9	0,45348	8	0,52503	9
1-C	0,74613	5	0,33592	4	0,65646	5
1-D	0,63548	15	0,65647	13	0,42908	16
1-E	0,64685	13	0,68906	14	0,45072	14
2-A	0,76951	2	0,37628	6	0,62063	6
2-B	0,70180	10	0,53977	10	0,48541	12
2-C	0,69931	11	0,60391	11	0,49959	11
2-D	0,84965	1	0,11111	1	0,70231	2
2-E	0,73952	6	0,42819	7	0,61674	7
3-A	0,76614	4	0,26984	3	0,68819	3
3-B	0,76767	3	0,11581	2	0,71783	1
3-C	0,64197	14	0,60401	12	0,51137	10
3-D	0,72698	7	0,35825	5	0,54221	8
3-E	0,72359	8	0,53673	9	0,65746	4
Unmordant	0,62901	16	0,69150	15	0,47259	13

In Table 5 the methods and rank results were aimed to be compared using three different multi-criteria decision making methods. The rank results obtained via VIKOR, GREY RELATIONAL ANALYSIS, and TOPSIS method show that because experimental application no. 2-D ranked the first (the best) by GREY RELATIONAL ANALYSIS and VIKOR method, the rank results were similar. In order to determine consistency between the rank results obtained via three different analysis methods, Spearman test is done. In the calculation below which was done to determine the consistency between GREY RELATIONAL ANALYSIS and VIKOR:

$$\rho = 1 - \left\{6.\left[\frac{\sum_{n=1}^{N}(d^n)^2}{N.(N^2-1)}\right]\right\}$$

$$\rho = 1 - \frac{6x54}{16(16^2-1)} = 0{,}92$$

ρ = -1 showed negative consistency (rank of x and y series in the reverse direction)
ρ = +1 showed positive consistency (rank of x and y series in the same direction)
ρ = 0 showed no consistency between x and y ranks.
(NOT: Consistency should be at least 1,46 Z minimum 50%.)

$Z = \rho.\sqrt{(N-1)}$ $\quad$ $Z = 0{,}92.\sqrt{(16-1)} = 3{,}565468469 > 1{,}46$

Table-6. Spearman Test Results - The Comparison of VIKOR-(V), GREY RELATIONAL-(G) and TOPSIS -(T) Methods' Ranks with each other for Choosing Mordant in Natural Dyeing with Tea Extract

	d=VIKOR-TOPSIS (V-T)		**d=GREY-TOPSIS (G-T)**		**d=GREY-VIKOR (G-V)**	
CODE	**SCORE**	**d^2**	**SCORE**	**d^2**	**SCORE**	**d^2**
1-A	1	1	-3	9	-4	16
1-B	-1	1	0	0	1	1
1-C	-1	1	0	0	1	1
1-D	-3	9	-1	1	2	4
1-E	0	0	-1	1	-1	1
2-A	0	0	-4	16	-4	16
2-B	-2	4	-2	4	0	0
2-C	0	0	0	0	0	0
2-D	-1	1	-1	1	0	0
2-E	0	0	-1	1	-1	1
3-A	0	0	1	1	0	0
3-B	1	1	2	4	2	4
3-C	2	4	4	16	2	4
3-D	-3	9	-1	1	2	4
3-E	5	25	4	16	-1	1
Unmordant	2	4	3	9	1	1
Σd^2		60	Σd^2	80	Σd^2	54
ρ		0,91	ρ	0,88	ρ	0,92
		91,18%		87,65%		92,06%
Z		3,53138	Z	3,39466	Z	3,56546

Spearman ρ co-efficient values vary between -1 and +1. The three values (ρ=-1 and ρ=+1 close values) show that the connection between the two variable ranks is very good. ρ<0 shows a negative change between the ranks, ρ>0 shows a positive change between the tanks and, ρ=0 shows there is no connection (consistency) between the ranks.

For average values of paired comparisons and methods, firstly, mutual methods are dealt with. Below is the average of T-TOPSIS comparison

V – T = 91,18%
G – T = 87,65%

The average of TOPSIS-T =
(0,9118+0,8765)/2=0,89415

V-T=	91,18%	GRA=	89,86%
G-T=	87,65%	TOPSIS=	89,42%
G-V=	92,06%	VIKOR=	91,62%

The consistency between VIKOR and TOPSIS methods was found to be 0,91, the consistency between GREY Relation and TOPSIS was found to be 0,87, and the consistency between GREY Relation and VIKOR was found to be 0,92.

It is accepted that with the result 0,92, which has the highest consistency, there is a very high rank consistency (similarity) between GREY RELATIONAL ANALYSIS and VIKOR methods.

It is also seen that VIKOR method has the highest average among the paired comparisons. In this sense, VIKOR method was put forward in our study and solution steps were shown.

According to the values obtained from 2-D experiment and computations done in this study 15% $KAl(SO_4)_2.12H_2O$ (Potassium aluminium sulphate- alum) is accepted to be the most appropriate mordant.

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