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Analysis of Some Factors Affecting the Growth of Castor Shrub and Suitability of its Seed Oil in Industrial Application

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Abstract

Some concern had been shown regarding the limited availability of castor seed to satisfy the rising yearning for its seed oil for use in industrial and domestic applications. This growing demand calls for refocus on backward integration in order to ensure sustained supply chain. This study adopts a factorial analysis that involves the use of Principal Component Analysis (PCA) and Kendall's Coefficient of Concordance (KCC) as statistical procedures to analyze some critical factors affecting the growth of castor shrub and its seed. KCC analyzed the degree of agreement among the fifteen Judges who ranked the thirty-two identified variables affecting the growth of castor shrub and the suitability of its seed oil in industrial application in descending order of importance. The result of the KCC showed an index of concordance in ranking as W=0.61 indicating 61% agreement among the 15 judges. The PCA helped to analyze the Judges responses arranged in form of data matrix that was facilitated by the use of statistiXL software. The PCA result revealed significant parsimony in data reduction from thirty-two to four principal factors creatively labeled: Seed oil particularities, Resource Conversion Efficiency, Plant-cooperation-oriented yield and Soil Condition respectively. The implication of this is that the principal factors that influence the growth of castor shrub and the suitability of its seed oil in industrial application has been identified.

Keywords: Castor Shrub, Backward Integration, Variables, Castor Seed, Growth

Introduction

Some concern had been expressed over the limited availability of castor seed to produce drying oil discovered to be a close substitute to sunflower oil that is currently being used for wood surface coating. Since castor seed has been found to be a good substitute for sunflower drying oil, the need therefore to ensure steady cultivation of the shrub and subsequent sustainable production of the oil has become imperative if for instance nations in Sub Sahara Africa are to improve their economy through manufacturing of surface coatings, polymers, lubricants for aircrafts, cosmetics, food seasoning, perfumery products, ointments, waxes, pharmaceuticals, printing inks, hair dressings, nylon, enamels, electrical insulations and disinfectants. Attention has been focused on using rubber seed as a substitute but the major problem with that policy approach is that it takes years for rubber to grow to maturity and to fructify. Even as of now, planting of castor seed is being done by subsistence farming in isolated areas of Sub-Saharan Africa. Moreover, the potential utilization of this oil is yet to be explored. Previous research has addressed the use of castor seed

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oil in various industrial applications but are yet to look into the area of backward integration that consider the best possible ways of growing this seed plant so as to generate sustained supply of the seed. According to Pommerening and Muszta (2015) Analyzing and modeling plant growth remains a vital "interdisciplinary field of plant science. The use of relative growth rates, involving the analysis of plant growth relative to plant size, has independently emerged in different research groups and at different times and has provided powerful tools for assessing the growth performance and growth efficiency of plants and plant populations". The authors reviewed and combined "existing methods of analyzing and modeling relative growth rates and applied a combination of methods to Sitka spruce (Picea sitchensis (Bong.) Carr.) stem-analysis data from North Wales (UK) and British Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) yield table data". The results obtained "showed that, by combining the approaches of different plant-growth analysis laboratories and using them simultaneously, we can advance and standardise the concept of relative plant growth". Vanaja et al. (2008) evaluated the "growth and yield responses of castor bean (Ricinus communis L.) to two elevated CO_2 levels (550 and 700 ppm)". The elevated CO_2 levels were found to "significantly increased the total biomass and yield of castor bean while enhanced CO_2 levels per se did not changed the content and quality of the castor oil".

The literature on the use of castor seed for industrial production is plentiful. Early studies on the use of castor seed dates back to mid-20th century when its dehydrating properties were not still well known but was punitively administered to war prisoners during the World war II by Italian Fascist leader Mussolini Benito (1883-1945). Trevino and Trumbo (2002) studied "the utilization of castor oil as a coating application by converting the hydroxyl functionalities of castor oil to β-ketoesters using *t*-butyl acetoacetate". Others include: Berman et al. (2011), Lima *et al.* (2011), Shojaeefard *et al.* (2013), Thakur and Karak (2013), Calegari *et al.* (2017) and Wang *et al.* (2017). Although "studies have shown promising results for the use of castor oil as a technically feasible biodiesel fuel, a major obstacle still exists in its use as a biodiesel in some countries such as Brazil. For example, in Brazil, government policies promoted castor as a biodiesel feedstock in an attempt to bring social benefits to small farmers in the semi-arid region of the country", see for example, Hall et al. (2009) and da Silva (2010). Furthermore, in recent years, "the oil is largely used in the specialty chemical industry worldwide, and the growth of its consumption is limited by insufficient and unreliable feedstock supply rather than by the industry demand" (Severino et al., 2012a and Mubofu, 2016). That said, regarding the models employed, the application has been widely described in literature such as Scott et al. (2003), Kongbonga et al. (2011), Jolliffe (2012), as well as Baran and Newman (2017). Principal component analysis (PCA) "is a useful tool that has been widely used for the multivariate analysis of correlated variables and also to analyze data in various fields, such as in administration, social sciences, engineering, chemistry and biology". In many studies such as that of Igboanugo et al., (2016) attempts was made to conjointly apply Kendall's coefficient of concordance as well as Principal component analysis (PCA) to analyze factors or unique variables that influence quality and productivity in fibre cement roofing sheet. Similar studies include: Meira et al. (2016), Goodarzi et al. (2011), Tomazzoni et al. (2013), Mueller et al. (2013), Karthil et al. (2014). Others are: Placide et al., (2015) and Anderson et al., (2017) respectively.

It is vividly clear from the foregoing review that past research on the use of PCA and KCC to analyze factors that influence castor shrub growth and the suitability of its seed oil in various industrial and domestic application appears limited. The major "advantage of PCA approach adopted is that it provides a correlation matrix that relativizes the interplay among the identified factors". This study is aimed at identifying some variables through literature that militate against or influence the growth of castor shrub and suitability of its seed oil in industrial application. The identified variables will rotate to form a cluster of related variables labeled as factors to give a better understanding of the way the variables inter correlated. In this way, policy framework on how to enhance the growth of the castor shrub and hence increase yield of the castor seed can be forged. It is hoped that the research outcome would guide backward integration so that sustained supply of castor seed can be achieved.

Materials and Methods

Materials

The primary data used in this study were the thirty-two (32) variables artistically selected from literature survey that militate against or influence the growth of castor shrub and suitability of its seed oil in industrial application.

Methods

Kendall's coefficient of concordance (KCC)

A mixed bag of variables, thirty-two in number artistically selected from literature survey, were used to craft set of questionnaires that were administered to knowledgeable respondents. Under this regime, first set of questionnaires were administered to twenty five (25) selected judges where only fifteen (15) who ranked the variables in descending order of importance were retrieved. The respondents' scores were used to form a data matrix of 15 by 32 in dimension. The degree of concordance among the judges was computed as W. A test statistic called chi square (X^2) helped to assess the significance level of the judges ranking. The X^2- test guided the application of hypotheses:

H_0: Judges ranking are discordant

H_1: Judges ranking are consistent

Decision Rule: if $X^2_{cal} > X^2_{tab}$, we say that we do not have sufficient evidence to accept the null hypothesis, H_0: and hence accept the alternate hypothesis.

The Kendall coefficient of concordance is given by

$$W = \frac{S}{\frac{1}{12}K^2(N^3 - N)} \quad (1)$$

where,

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2$$

R_j = The Column sum of ranks

N = The total number of Variables

S = Variance

K = The number of Judges

The ranking by the judges were polled to obtain a sequence of well-ordered scale items.

Principal Component Analysis (PCA)

The second set of questionnaires that also contains 32 critical variables were administered to one hundred and thirty (130) respondents where only hundred (100) were retrieved for their expert evaluations. The factorial analysis of the respondent's scores collated as data matrix were solved using StatistiXL software. The output of the analysis include the following: Scree plot, factor plot, correlation matrix, eigenvalues, eigenvector, descriptive Statistic, unrotated factor loading, varimax rotated factor loadings, case-wise factor scores, explained variance among others. Factor matrix interpretation was rendered based on the StatistiXL outputs.

From the data matrix the correlation matrix was obtained using Equation (2) as stated below:

$$r_{ij} = \frac{\sum xy}{\sqrt{\left(\sum x^2\right)\left(\sum y^2\right)}} \quad (2)$$

where, $x = X_{ij} - \bar{X}_{.j}$

$$y = Y_{ij} - \bar{Y}_{.j}$$

$$\bar{X}_{.j} = \frac{\sum_{i=1}^{N} X_{ij}}{N}$$

$$\bar{Y}_{.j} = \frac{\sum_{i=1}^{N} Y_{ij}}{N}$$

$$N = n_j = I = i_{\max}$$

$$J = j_{\max}$$

Results and Discussion

Result of Kendall Coefficient of concordance (KCC)

To calculate the Kendall's coefficient of concordance *(W)*, equation 1 was used as follows:

$$W = \frac{S}{\frac{1}{12}K^2(N^3 - N)}$$

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2$$

From Factor Ranking Matrix

From Factor Ranking Matrix

$$\sum R_j = 7{,}923$$

$$\frac{\sum R_j}{N} = \frac{7{,}923}{32} = 247.59$$

$$S = \sum\left(R_j - \frac{\sum R_j}{N}\right)^2 = 376{,}032.75$$

Therefore $W = \frac{376{,}032.75}{\frac{1}{12}\times 15^2(32^3 - 32)} = \frac{376{,}032.75}{613800} = 0.61$

This result indicates that 61 percent agreement was observed among the 15 judges.

Also, χ^2_{cal} = K (N – 1) W (3)

where, K = 15, N = 32, W = 0.61

$$\therefore \chi^2 = 15(32 - 1)0.61 = 283.65$$

Test of Hypothesis:

H_0: The ranking of the fifteen (15) judges are discordant.

H_1: The ranking of the fifteen (15) judges are consistent.

Since $X^2_{cal}=283.65 > X^2_{tab}=44.97$, we reject the null hypothesis (H_0) and accept the alternate hypothesis. This infer that the judges ranking of the 32 variables were consistent.

Table 1 depicts the merit order sequentiality of the 32 variables ranked by the fifteen Judges and analyzed with Kendall coefficient of concordance. The R_js determine the ranking order.

Table 1. Merit order sequentiality of 32 variables for castor shrub growth

S/N	R_j	Variables	S/N	R_j	Variables
1	45	Soil Composition	17	276	Intermolecular force
2	61	Adhesion force	18	278	Storage stability
3	78	Raw material	19	290	Type of Alkyd Resin
4	88	Good shelf life	20	293	Chemical Oxidation
5	117	High Cohesive Strength	21	301	Blend of Driers
6	123	Environmental factor	22	314	Right raw materials
7	136	Trans-esterification	23	319	Reaction Temperature
8	138	Surface Coating	24	328	Moisture content
9	159	Soil Nutrient	25	329	Type of solvent
10	164	Capital Intensive	26	351	Solubility
11	174	Type of Fertilizer	27	352	Physicochemical Properties
12	208	Seed dormancy	28	375	Intercropping
13	249	Disease	29	391	Refining
14	252	Mode of Extraction	30	392	Soaking
15	254	Production Process	31	408	Heating
16	255	Dehydration	32	410	Seed Varieties

Result of the Principal Component Analysis (PCA)

The data obtained from the second questionnaire were arranged in matrix form based on the 5–point Resis-Likert scale. The scree plot showing the elbow at (3, 1) is depicted in Figure 1. It is obvious from the scree plot in Figure 1 that at eigenvalue of 1, and component number 3, the curvity tends to flatten out, suggesting that four factors extracted are adequate. This demonstrate a significant parsimony in factor reduction from 32 to mere 4.

The result of the varimax rotated factor matrix is depicted in Table 2.

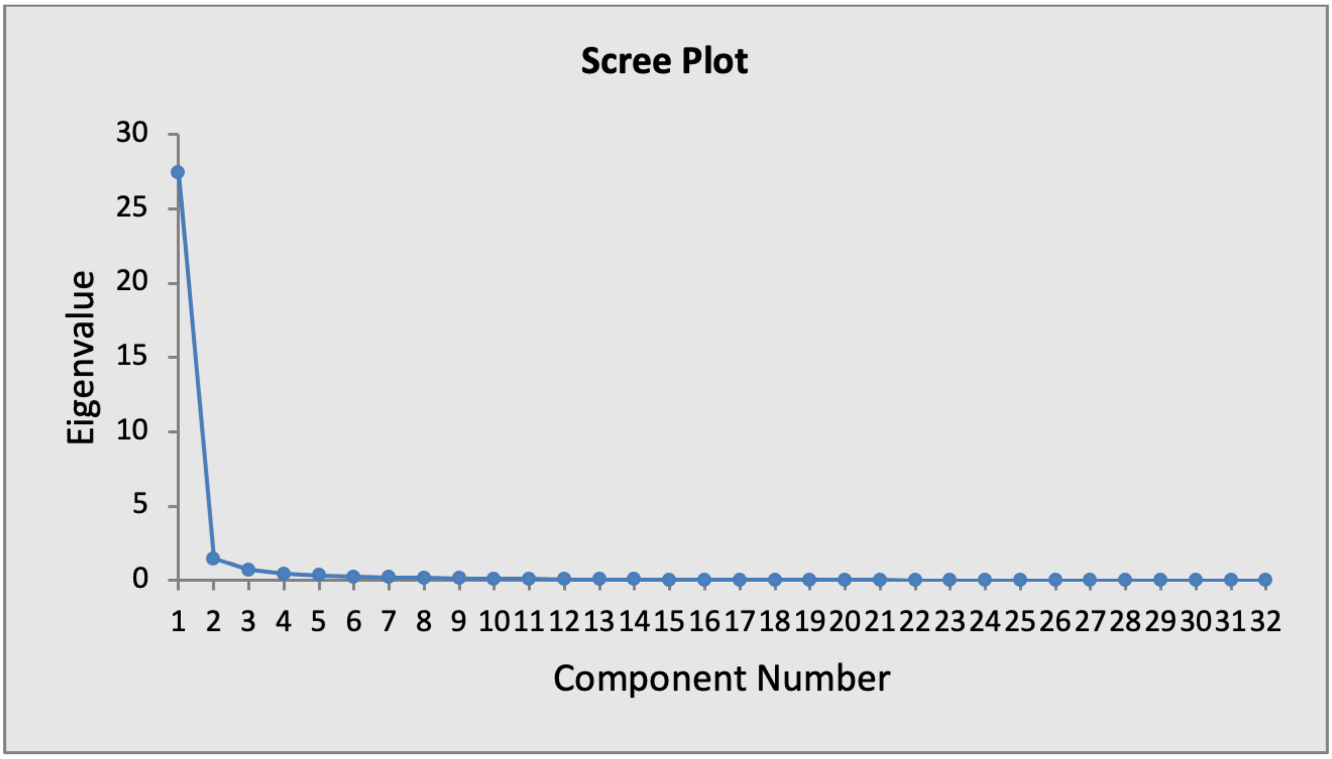

Figure 1. Scree Plot

Table 2. Varimax Rotated Factor Loadings matrix of 32 variables for surface coating manufacture

S/N	Variables	Factor 1	Factor 2	Factor 3	Factor 4
1	Soil Composition	0.406	0.490	0.247	0.716
2	High Cohesive Strength	0.456	0.824	0.207	0.090
3	Environmental Factor	0.791	0.453	0.178	0.256
4	Raw Material	0.462	0.574	0.301	0.317
5	Production Process	0.734	0.540	0.164	0.156
6	Trans-esterification	0.738	0.541	0.246	0.171
7	Seed dormancy	0.460	0.807	0.172	0.183
8	Type of Fertilizer	0.740	0.549	0.166	0.207
9	Soaking	0.388	0.726	0.199	0.407
10	Solubility	0.571	0.516	0.414	0.236
11	Adhesion Force	0.423	0.825	0.172	0.203
12	Good Shelf Life	0.358	0.697	0.315	0.327
13	Physicochemical Properties	0.636	0.393	0.548	0.268
14	Surface Coating	0.815	0.380	0.234	0.263
15	Dehydration	0.830	0.423	0.209	0.124
16	Blend of Driers	0.435	0.812	0.177	0.232
17	Type of Alkyd Resin	0.514	0.616	0.291	0.131
18	Chemical Oxidation	0.734	0.419	0.216	0.178
19	Disease	0.487	0.779	0.245	0.121
20	Reaction Temperature	0.507	0.787	0.205	0.125
21	Soil Nutrient	0.401	0.767	0.213	0.267
22	Intermolecular Force	0.792	0.506	0.159	0.175
23	Moisture Content	0.621	0.450	0.488	0.279
24	Storage Stability	0.497	0.582	0.298	0.186
25	Type of Solvent	0.779	0.482	0.192	0.141
26	Raw Material Formulation	0.392	0.758	0.231	0.326
27	Intercropping	0.648	0.306	0.627	0.220
28	Capital Investment	0.757	0.392	0.233	0.192
29	Refining	0.364	0.636	0.325	0.378
30	Mode of Extraction	0.720	0.400	0.395	0.257
31	Seed Varieties	0.808	0.416	0.223	0.252
32	Heating	0.566	0.728	0.146	0.198

Factor Interpretation

As explained under the methods section, Varimax rotation enhances better redistribution of factors as to promote factor interpretability. The scree plot of Figure 1 indicates that at the elbow (3, 1), Factors 1, 2 and 4 stand out. However, Factor 3 wielded substantial complementary loading which it shared with Factor 1 under physicochemical properties and intercropping (serial numbers 13 and 27 respectively). In this way, the 32 variables clustered under four factors – a significant reduction in variables dimension.

Factor 1: Seed Oil Particularities

This regime clustered 16 variables. All the factor loadings are positive. It is therefore a principal stocky factor providing relevant information about the physicochemical properties of the castor shrub and its seed. The utmost dominant variable, judging by its factor loading of 0.830, is dehydration. This could be due to the fact that castor oil, when consumed, has dehydrating effects because the oil induces diarrhea. Benito Mussolini, the Italian despotic leader, administered it as punishment to political dissenters who, after consuming certain quantities, began to experience its laxative effects. However at moderate uses, castor oil has alternative medicinal uses. Again, "castor oil is not a drying oil, meaning that it has a low reactivity towards air compared to other drying oils like linseed oil and tung oil. Thus dehydration of castor oil gives linoleic acids, which do have drying properties". Furthermore, one of the useful seed oil particularities is its suitability for the manufacture of surface coatings such as wood varnish and paints. The high factor loading of 0.815 (Surface Coating), next to dehydration (0.830), shows the industrial importance of castor seed oil. The rest factor loadings indicate the importance of the variable under this factor.

Table 3. Clusters 1(Factor 1): Seed Oil Particularities

Factor 1: Seed Oil Particularities		
Variable Number	Variable Description	Factor Loading
3	Environmental Factor	0.791
5	Production Process	0.734
6	Trans-esterification	0.738
8	Type of Fertilizer	0.740
10	Solubility	0.450
13	Physicochemical Properties	0.636
14	Surface Coating	0.815
15	Dehydration	0.830
18	Chemical Oxidation	0.734
22	Intermolecular Force	0.792
23	Moisture Content	0.621
25	Type of Solvent	0.779
27	Intercropping	0.648
28	Capital Investment	0.757
30	Mode of Extraction	0.720
31	Seed Varieties	0.808

Table 4. Clusters 2 (Factor 2): Resource Conversion Efficiency

Factor 2: Resource Conversion Efficiency		
Variable Number	Variable Description	Factor Loading
2	High Cohesive Strength	0.824
4	Raw Material	0.574
7	Seed Dormancy	0.807
9	Soaking	0.726
11	Adhesion Force	0.825
12	Good Shelf Life	0.697
16	Blend of Driers	0.812
17	Type of Alkyd Resin	0.616
19	Disease	0.779
20	Reaction Temperature	0.787
21	Soil Nutrient	0.767
24	Storage Stability	0.582
26	Right Raw Material	0.758
29	Refining	0.636
32	Heating	0.728

Factor 2: Resource Conversion Efficiency

Cluster 2 is creatively labelled Resource Conversion Efficiency. Top three variables include: Adhesion force (0.825), High cohesive strength (0.824) and blend of driers employed (0.812) which principally showed the industrial importance of castor seed oil under the resource conversion efficiency. These variables are critical under this factor. Next to this trio of variable is seed dormancy (0.807). The variable caveats that if the seed stays unused for certain length of time, it might go rancid and thereby affect its physiochemical properties. As earlier stated, other variables under this factor exercise influence according to the level of the factor loading they wield.

Factor 3: Plant-cooperation-oriented yield

The third factor creatively labelled Plant-cooperation-oriented yield suggests that physicochemical properties as well as intercropping wield middling factor loading indicating that intercropping affects the quality of seed of castor plant and thus influence the growth of the seed as well as the physicochemical properties of the seed oil that influences its industrial importance.

Factor 4: Soil Condition

Cluster 4 is creatively labelled Soil Condition.

Table 5. Clusters 3 (Factor 3): Plant-cooperation-oriented yield

Factor 3: Plant-cooperation-oriented yield		
Variable Number	Variable Description	Factor Loading
13	Physicochemical Properties	0.636
27	Intercropping	0.648

Table 6. Clusters 4 (Factor 4): Soil Condition

Factor 2: Soil Condition		
Variable Number	Variable Description	Factor Loading
1	Soil Composition	0.716

Finally, there is soil condition as a lone factor. This suggests that fertilization, depending on the prestine condition of the soil, is an important consideration in castor plant plantation.

Conclusion

This study has been able to identify thirty two (32) important variables affecting the growth of castor shrub and the suitability of its seed oil in industrial application. The Kendall’s Coefficient of Concordance (KCC) model used was able to evaluate the level of agreement among the knowledgeable respondents (Expert Judges) that ranked the variables in merit order of sequentiality. The Principal Component Analysis (PCA) model adopted helped to reduce the large sum of the data from thirty-two (32) to four (4). This implies that a considerable parsimony was achieved in terms of data summarization. The PCA analysis show that 4 principal factors creatively labeled: Seed oil particularities, resource conversion efficiency, plant-cooperation-oriented yield and soil condition respectively, represent the principal factors affecting the growth of castor shrub and the suitability of its seed oil in industrial application.

Compliance with Ethical Standards

Conflict of interest

The author solemnly declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

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Data availability

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Consent for publication

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