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RESEARCH PAPER

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Study the relationships between seed cotton yield and yield component traits by different statistical techniques

Ashraf Abd El-Aala Abd El-Mohsen*, Mohamed Mostafa Amein

Department of Agronomy , Faculty of Agriculture, Cairo University, Giza, Egypt

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Key words: Egyptian cotton, seed cotton yield, correlation and regression analysis, stepwise multiple regression, path and factor analysis.

Abstract

Two field experiments were conducted in 2013 and 2014 growing seasons at the experimental farm of the Faculty of Agriculture, Cairo University, Giza, Egypt. Twenty Egyptian cotton genotypes were evaluated in a randomized complete blocks design with three replications for six traits. The aim of this study was to determine the relationships between seed cotton yield and yield components and to show efficiency of components on seed cotton yield by using different statistical procedures. Data of seed cotton yield and yield components over the two years in the study were evaluated by statistical procedures; correlation and regression analysis, path coefficient analysis, stepwise multiple linear regression and factor analysis. Differences among all the traits were statistically highly significant. Seed cotton yield plant^{-1} was significantly and positively correlated with number of bolls plant^{-1} (r = 0.85**), boll weight (r = 0.68**), seed index (r = 0.91**) and lint percentage (r = 0.70**). Regression analysis by using step-wise method revealed that 96.51 percent of total variation exist in seed cotton yield accounted for by traits entered to regression model namely; number of bolls plant^{-1}, boll weight and lint percentage. The path analysis indicated high positive direct effect of number of bolls plant^{-1} (0.57), boll weight (0.39) and lint percentage had moderate positive direct effect (0.24) on seed cotton yield plant^{-1}. Factor analysis indicated that three factors could explain approximately 73.96% of the total variation. The first factor which accounted for about 53.21% of the variation was strongly associated with number of bolls plant^{-1}, boll weight, seed index and lint percentage, whereas the second factor was strongly associated and positive effects on earliness index only, which accounts for about 20.75% of the variation. Stepwise multiple regression and path analysis techniques were more efficient than other used statistical techniques. Based on the five of statistical analysis techniques, agreed upon that high seed cotton yield of Egyptian cotton could be obtained by selecting breeding materials with high number of bolls plant^{-1} , boll weight and lint percentage.

* **Corresponding Author:** Ashraf Abd El-Aala Abd El-Mohsen ✉ dr_ashraf200625@yahoo.com

Introduction

Cotton (*Gossypium barbadense* L.) is an important cash crop of Egypt. It enjoys prominent position in the economic perspective of Egypt for its value and potential in strengthening the nation's economy.

The cultivated area of cotton is going lower year after year, in spite of its importance for national economy. Egyptian statistics indicate that the decrease of cotton cultivated area from 993 thousand feddans in 1990 to about 288 thousand feddans in 2015, led to a decrease in cotton production. One of the lowest cotton cultivated area, due to unfair prices to producers and better net profits from alternatives crops especially cereal crops, at the same time increase of costs of cotton inputs. In addition to the very high cost of hand picking and insufficient trained picking workers. The decrease of cotton production in recent years has a negative reflection on local and international market supply. Also, low production is attributable to the scarcity of proper cotton varieties with high quality. The evaluation of different varieties of cotton and selection of appropriate varieties using multiple attributes can help farmers in choose needed varieties and thereby increase the performance.

Sustainable cotton production in the future will depend on the development of cotton varieties with higher yield potential and quality of seed cotton as well as better tolerance to biotic and abiotic stresses. Nevertheless, the need for further amplified efforts for continued genetic improvement of cotton is even greater today than before in the face of low production per unit area in Egypt as compared to other advanced cotton-growing countries of the world. A breeder usually records data on the basis of selection of desired economic traits for which positive or negative correlation may exist. The understanding of the correlation of factors influencing yield is a pre-requisite for designing an effective plant breeding programme.

Different statistical techniques have been used in modeling crop yield, including correlation, regression and path coefficient analyses, and factor and cluster analyses to evaluate yield and yield components for breeding programs (Massmart *et al.,* 1997; Ikiz *et al.,* 2006).

Correlation and regression analysis of seed cotton yield and its contributing components are very important in determining suitable selection criteria for the improvement of seed cotton yield. A thorough knowledge about the nature, mean performance, extent of relationship and correlation of yield with various agronomic characters is indispensable for breeder to tackle the problem of yield increase successfully.

Information on the strength and direction of component characters with seed yield and also inter correlation among themselves would be very useful in formulating an effective selection criteria for improvement of yield. Determination of correlation coefficients between various characters helps to obtain best combinations of attributes in cotton crop for obtaining higher return per unit area.

A simple measure of correlation of characters with yield is inadequate, as it will not reflect the direct influence of component characters on the yield. Thus, it is necessary to split the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959). This would help to identify with certainty the component traits to be relied upon during selection to improve seed yield. Such an attempt was made in the present study.

Multivariate statistics concern understanding the different aims and background, and explain how different variables are related with each other. The practical implementation of multivariate statistics to a particular problem may involve several types of univariate and multivariate analyses in order to understand the relationships among variables and their relevance to the actual problems being studied (Johnson and Wicheren, 1996). Many different multivariate analyses such as path coefficient, stepwise multiple linear regression and factor analyses are available.

Keeping these points in view this study was undertaken in order to determine the dependence relationship between seed cotton yield and yield component characters of twenty Egyptian cotton genotype by using five statistical procedures including; simple correlation and regression, path analysis, stepwise multiple linear regression and factor analysis.

Materials and methods

Location of Study and Plant Materials

Two field experiments were conducted in 2014 and 2015 growing seasons at the experimental farm of the Faculty of Agriculture, Cairo University, Giza, Egypt (30° 02'N Latitude and 31° 13' E Longitudes, Altitude 22.50 m). Five statistical procedures including; correlation, multiple linear regression, stepwise multiple linear regression, best subset regression, and factor and cluster analysis were used to study the relationship between cotton yield and its components. The genetic materials used in this experiment included twenty Egyptian cotton cultivars (*Gossypium barbadense* L.) representing a wide range of variability in their agronomic traits. Seeds of all genotypes were obtained from Cotton Research Institute, Agricultural Research Center, Giza, Egypt. Pedigree and the descriptions of the twenty Egyptian cotton genotypes are shown in Table 1.

Table 1. Pedigree and the descriptions of the twenty Egyptian cotton genotypes.

Genotypes	Pedigree	Characteristics
Ashmouni	Ashmouni	Long staple variety, characterized by high in lint %, micronaire value, fiber strength and uniformity index.
Menoufi	Selection from G.36	Long staple variety, characterized by high in fiber strength
Dandara	Selection from G.3	Long staple variety, characterized by high in boll weight, fiber strength and earliness.
Giza 45	G.28 x G.7	Extra long staple variety, characterized by high in fiber length, uniformity index, micronaire value and fiber strength.
Giza 70	G.59 A x G.51 B	Extra Long staple variety, characterized by high in micronaire value and earliness.
Giza 75	G.67 x G.69	Long staple variety, characterized by micronaire value and fiber strength.
Giza 76	Menoufi x Pima	Extra Long staple variety, characterized by high in fiber strength and earliness.
Giza 77	G.70 x G.68	Extra Long staple variety, characterized by high in earliness, micronaire value, fiber strength and uniformity index.
Giza 80	G.66 x G.73	Long staple cultivar, characterized by high in earliness, lint % and fiber strength.
Giza 83	G.72 x G.67	Long staple variety, characterized by high in earliness and lint %.
Giza 85	G.67 x G.58 S B	Long staple variety, characterized by high lint %.
Giza 86	G.75x G.81	Long staple cultivar, characterized by high lint %.
Giza 87	(G.77 x G.45)A	Extra long staple cultivar, characterized by high in boll weight, fiber length, micronaire value and fiber strength.
Giza 88	(G.77 x G.45)B	Extra long staple cultivar, characterized by high in boll weight, fiber length, micronaire value and fiber strength.
Giza 89	G.75 x G.6022 Russian	Long staple variety, characterized by high in lint %, micronaire value and fiber strength.

Genotypes	Pedigree	Characteristics
Giza 90	G.83 x Dandara	Long staple cultivar, characterized by high in earliness, fiber length and micronaire value.
Giza 92	Giza 84 (Giza 74 x Giza 68)	Extra long staple variety, characterized by micronaire value and fiber strength.
Pima S4	American Egyptian variety	Long staple variety, characterized by high in earliness, lint % and uniformity index
Pima S6	American Egyptian variety (5934-23-2-6) x (5903-98-4-4)	Long staple variety, characterized by high in earliness and fiber strength.
Pima S7	American Egyptian variety (6614-91-9-3) x (6907-513-509-501)	Long staple variety, characterized by high boll weight.

Experimental Design and cultural practices

The field trial was laid out in a Randomized Complete Blocks Design (RCBD) with 3 replications. The genotypes were allotted randomly to the 20 plots of each replication. The experimental unit area was 7.8 m^2 consisting of consisted of 4 rows, 3 m long and 65 cm apart. The spacing between the plants on the rows was 20 cm, having 40 plants. The field trial was run during the 2014 and 2015 growing seasons.

The preceding crop was wheat in both seasons of the study. The seeds were planted on 15 April 2014 and on 13 April 2015 by hand in both seasons. Seedlings were thinned 20 days after sowing to secure two plants per hill. The other cultural practices were carried out according to the common practices in cotton fields Nitrogen (60 kg N/fed.), as ammonium nitrate (33.5% N), and potassium (48 kg K_2O/fed.), as potassium sulphate (48% K_2O), were side dressed before the first and the second irrigations. Phosphorus (30 kg P_2O_5/fed) as super phosphate (15.5% P_2O_5) was broadcasted during seedbed preparation. Other inputs like irrigation were applied at proper times and insecticides as and when required. All the cultural practices including weeding, etc. were adopted uniformly in the whole experiment throughout the growing period.

Data collection

For data collection, at harvesting ten individual plants were selected at randomly from the central rows in each plot and marked before harvesting and used as a sample to measure the following traits:

Number of bolls per plant (x_1): as the average number of bolls counted from the same sample plants.

Boll weight (x_2): as the weight of 50 bolls picked randomly.

Seed index (g) (x_3): as the weight in grams of 100 seeds.

Lint percentage (%) (x_4): calculated from the formula: Lint percentage = (Weight of lint cotton yield in the sample/Weight of seed cotton yield) x 100.

Earliness index (%) (x_5): expressed as yield of the first pick x 100/total seed cotton yield.

Seed cotton yield per plant (g) (y): estimated as average weight of seed cotton yield in grams.

Statistical analysis and interpretation of data

Basic statistics: The raw data was compiled by taking the means of all the plants taken for each treatment and replication for different traits in both the experimental years. The pooled means of both seasons were subjected to further statistical and biometrical analysis. Simple statistical parameters, viz. average, range, standard deviation and coefficient of variation were analyzed according to Steel *et al.* (1997).

Analysis of variance: The data regarding different traits in each genotype were averaged and all the recorded data were subjected to analysis of variance (ANOVA) technique for a Randomized Complete Blocks Design (RCBD) as outlined by as mentioned by Gomez and Gomez (1984) through MSTAT-C computer programme (Freed *et al.,* 1989) for all the traits to test the null hypothesis of no differences among the cotton genotypes. Data were tested for violation of assumptions underlying the ANOVA. Data for the 2 years was tested for homogeneity using Bartlett's (1937) test of homogeneity and it was found to be homogeneous so the data were combined for analysis. The combined ANOVA was carried out according to Steel *et al.* (1997), to estimate the main effects of the different sources of variation and their interactions.

Simple correlation and regression analysis: To analyze the relationships between grain yield and yield components accurately, correlation and regression analysis was performed for all genotypes using the INFOSTAT version 9.0 (Di Rienzo, 2010) software statistical package. The data over two years subjected to estimate correlation and regression coefficients among measured characteristics. Correlation and regression analysis were determined according to methods developed by Snedecor and Cochran (1980).

Path coefficient analysis: Path coefficient analysis partitions correlation coefficients into direct and indirect effects through alternate pathways. Path coefficient analysis was done following to the method suggested by Dewey and Lu (1959). The direct and indirect effects were classified based on scale given by Lenka and Mishra (1973) (Table 2).

Table 2. A scale of the direct and indirect effects values and their rate of scale according to Lenka and Mishra (1973).

Values of direct and indirect effects	Rate of scale
0.00-0.09	Negligible
0.10-0.19	Low
0.20-0.29	Moderate
0.30-0.99	High
More than	Very high

The path coefficient analysis was performed by examining seed cotton yield plant^{-1} as a dependent variable for major contributor's traits to seed cotton yield plant^{-1} via INFOSTAT version 9.0, a computer program, as suggested by (Di Rienzo, 2010).

Stepwise multiple linear regression analysis: The stepwise multiple linear regression as applied by Draper and Smith (1981), was used to compute a sequence of multiple regression equations in a stepwise manner. Stepwise multiple linear regression procedure was used to determine the variable accounting for the majority of total yield variability. Stepwise program computed a sequence of multiple linear regression in a stepwise manner using MINITAB (2015) V. 16 software statistical package. At each step, one variable was added to the regression equation. The added variable was the one that induced the greatest reduction in the error sum of squares. It was also the variable that had the highest partial correlation with the dependent variable for fixed values of those variables already added. Moreover, it was the variable which had the highest F-value. To detect presence of multicolinearity, value of variance inflation factor (VIF) among all independent variables is often used (Hair *et al.*, 1995). [VIF= $1/(1- R_i^2)$, where $R_i^2$is the coefficient of determination for the prediction of the ith variable by the predictor variables]. Thus, large VIF's values (above 10) indicate high colinearity (Hair *et al.,* 1995).

Factor analysis: Factor analysis can be understood as a data reduction technique by removing the duplicated information from a set of correlated variables (Brejda, 1998). Factor analysis provides more information than a simple correlation matrix because it discriminates between groups of variables (factors) and indicates percentage contribution of variables to each factor (Seiler and Stafford 1985).

The Kaiser-Meyer-Olkin is the measure of sampling adequacy, which varies between 0 and 1. The values closer to 1 are better and the value of 0.6 is the suggested minimum. The Bartlett's Test of Sphericity is the test for null hypothesis that the correlation matrix has an identity matrix. Taking this into consideration, these tests provide the minimum standard to proceed for Factor Analysis. In the present study we used the principal component solution (Kim, 1974) and the varimax rotation extraction. Factor analysis was performed by using SPSS for Windows, version 17.0.0. (2009).

Results and discussion

Descriptive analysis

Basic statistical parameters: minimum and maximum values, mean values, standard deviation and coefficient of variation for twenty Egyptian cotton genotypes under investigation of all studied traits are presented in (Table 3). The coefficient of variation (CV %) is a good base for comparing the extent of variation. In addition, the CV% is a parameter which is not related to unit of measured traits and will be effective in comparing of the studied traits. CV% between different characters with different scales is shown in Table 3.

The CV% of the traits varied from 4.77 % (for lint percentage (%)) to 23.85 % (for seed cotton yield per plant (g)). The results show that the coefficient of variation was the highest for seed cotton yield per plant^{-1}, followed by number of bolls per plant^{-1}. Lint percentage (%) had the lowest value, followed by Seed index (g). Boll weight (g) and earliness index (%) showed moderate values for the coefficient of variation. Similar results have been reported by El-Kady *et al.* (2015).

Table 3. Basic statistical parameters for yield and its components in wheat cultivars: minimum (Min) and maximum values (Max), mean values, standard deviation (S.D) and coefficient of variation (C.V) across two years.

Traits	Min.	Max.	Mean	S.D	C.V%
Number of bolls per plant (x_1)	11.32	22.21	16.49	3.88	23.55
Boll weight (g) (x_2)	1.99	3.11	2.53	0.33	13.17
Seed index (g) (x_3)	8.72	11.16	9.92	0.63	6.40
Lint percentage (%) (x_4)	34.51	40.35	37.74	1.80	4.77
Earliness index (%) (x_5)	47.82	82.10	65.85	9.07	13.77
Seed cotton yield per plant (g) (y)	24.68	60.89	42.49	10.13	23.85

Key note for Table 3: S.D = standard deviation; C.V%=Coefficient of variation.

Means of seed cotton yield plant^{-1} varied between 24.68 and 60.89 g per plant. Number of bolls plant^{-1} ranged from 11.32 to 22.21. Boll weight was between 1.99 and 3.11 g, whereas seed index was between 8.72 and 11.16 g, lint percentage (%) and earliness index (%) were between 34.51 and 40.35 %, 47.82 and 82.10, respectively (Table 3). Such considerable range of variations provided a good opportunity for yield improvement. This provides evidence for sufficient variability and selection on the basis of these traits can be useful. Selection for seed cotton yield can only be effective if desired genetic variability is present in the genetic stock. El-Kady *et al.* (2015) studied Egyptian cotton cultivars and found high variability for seed cotton yield and its components. Present data is in agreement with results obtained by Ahuja *et al.* (2006) and Alishah *et al.* (2008).

Combined analysis of variance for yield and yield components traits

The data was tested for normality and uniformity of variance. Then, analysis of variance based on randomized complete block design (RCBD) was performed (Table 4). Coefficient of variation is an important parameter related to accuracy of the experiment provided it is less than 20% (Gomez and Gomez, 1984). The coefficient of variation (CV %) is a good base for comparing the extent of variation. In addition, the CV% is a parameter which is not related to unit of measured traits and will be effective in comparing of the studied traits. In the present study, CV% between different characters with different scales is shown in Table 2. The CV% of the traits varied from 0.85 % (for lint percentage (%)) to 8.38% (for seed index (g)) and were therefore in the acceptable range as commonly observed in field experiments and showing the validity of the experiment.

Table 4. Mean squares corresponding to various sources of variation for grain yield and other traits in some wheat cultivars over the two studied seasons.

SOV	df	Number of bolls per plant	Boll weight (g)	Seed index (g)	Lint percentage (%)	Earliness index (%)	Seed cotton yield per plant (g)
		Mean squares					
Years	1	0.004ns	0.103^{ns}	0.401^{ns}	0.716 **	18.897^{ns}	214.455**
Replications/years	4	1.928	0.024	0.527	0.045	5.268	8.503
Cultivars	19	80.541**	0.669**	2.422**	19.517**	494.034**	616.344 **
Cultivars x Years	19	2.379**	0.021**	0.698ns	0.128^{ns}	8.476**	22.362**
Error	76	0.419	0.004	0.692	0.104	1.856	8.126
Coefficient of Variation		3.98%	2.51%	8.38%	0.85%	2.07%	6.71%

Key note for Table 4: ns = Non significant and ** = Significant at P ≤ 0.01 .

As seen in Table 4, mean squares from combined analysis of variance (ANOVA) revealed highly significant (p<0.01) differences among 20 Egyptian cotton genotypes for 6 characters indicating the existence of sufficient variability among the genotypes for characters studied, this provides for selection from genotypes and the genetic improvement of this crop. Highly significant difference between the years were only observed for lint percentage (%) and seed cotton yield per plant (g). There was highly significant interaction effects between genotypes and years for all characters except seed index (g) and lint percentage (%). Although, the magnitude of the interactions mean square was relatively small in comparison to main effect. Soomro *et al.* (2005) and Copur (2006) also compared the yield and yield components of cotton cultivars and showed significant differences for these traits. Suinaga *et al.* (2006) and Meena *et al.* (2007) also evaluated the *Gossypium hirsutum* cultivars and hybrids, and observed varied values for seed cotton yield plant^{-1} and number of bolls plant^{-1}.

Analysis of correlation and regression

Correlation and regression analysis is a statistical tool for the investigation of relationships between variables. Regression analysis is shown in Table 5, where yield contributing traits were regressed on seed cotton yield per plant. R^2 shows the dependency of Y (dependent variable) upon x (independent variable), while regression coefficient shows that a unit change in x variable will bring change in Y variable. Correlation coefficients (r), coefficients of determination (R^2), regression coefficients (b) and their regression lines developed are presented in (Fig. 1 to 4 and Table 5).

Table 5. Correlation and regression coefficient between seed cotton yield plant^{-1} and its components of Egyptian cotton across two years.

Parameter	Correlation coefficient	Regression coefficient	Determination coefficient	Linear regression equation $\hat{Y} = Seed\ cotton\ yield\ plant^{-1}$
(x_1)	0.85**	2.21**	0.72	$\hat{Y} = 6.00 + 2.21x_1$
(x_2)	0.68**	20.57**	0.46	$\hat{Y} = -9.64 + 20.57x_2$
(x_3)	0.91**	14.50**	0.83	$\hat{Y} = -101.34 + 14.50x_3$
(x_4)	0.70**	3.91**	0.48	$\hat{Y} = -104.98 + 3.91x_4$
(x_5)	0.14^{ns}	0.15^{ns}	0.02	$\hat{Y} = 32.35 + 0.15x_5$

Key note for Table 5: ns,*and** = Non-significant, Significant at P ≤ 0.05 and 0.01, respectively. (x_1)= Number of bolls plant^{-1}, (x_2)= Boll weight (g), (x_3)= Seed index (g), (x_4)= Lint percentage (%), (x_5)= Earliness index (%).

Number of bolls plant^{-1} is the major yield contributing component having strong correlation with seed cotton yield. For the improvement of this trait, it was generally observed that an increase in boll number in cotton plant will eventually increase the seed cotton yield.

When we look at the results of analysis of correlation and regression coefficients between seed cotton yield and some of yield components, the results shown in Table 5 show that highly significant (p<0.01) and positive correlation (r=0.85**) was noticed for number of bolls plant^{-1} with seed cotton yield plant^{-1} (Table 5). When number of bolls plant^{-1} were regressed on seed cotton yield plant^{-1}, the coefficient of determination R^2 was 0.72, while the regression coefficient was 2.21 (Fig. 1 and Table 5). Results enunciated that a unit increase in the number of bolls plant^{-1} will lead to a matching increase in the seed cotton yield plant^{-1}. This indicated that seed cotton yield plant^{-1} was highly influenced by number of bolls plant^{-1}. Our findings were in accordance with the results of Soomro *et al.* (2005) and Copur (2006) who reported that the higher lint yields of cultivars were mainly caused by higher number of bolls per plant. They recommended selection for large bolls with high yields in cotton crop. DeGui *et al.* (2003) studied the effects of genetic transformation on the yield and yield components and concluded that higher yields of cultivars were mainly caused by higher number of bolls plant^{-1}.

As can be seen from Table 5, boll weight displayed a highly significant (p<0.01) positive correlation (r=0.68**) with seed cotton yield per plant. The coefficient of determination (R^2=0.46) determined that boll weight was responsible for 46% variation in seed cotton yield plant^{-1}. The regression coefficient (b=20.57) indicated that a unit increase in boll weight resulted into corresponding increase of 20.57 gms in seed cotton yield per plant (Fig. 2 and Table 5). Afiah and Ghoneim (2000) mentioned that seed cotton yield was positively correlated with bolls per plant, boll weight and lint yield. Khadijah *et al.* (2010) also, reported that bolls plant^{-1}, and boll weight were positively correlated with seed cotton yield.

Seed index is also an important yield component and plays imperative role in increasing the seed cotton yield. Results revealed that highly significant (p<0.01) positive correlation (r=0.91) was displayed by seed index with seed cotton yield plant^{-1}, which showed that seed cotton yield plant^{-1} was greatly influenced by seed index. The coefficient of determination (R^2=0.83) revealed 83 %variation in the seed cotton yield per plant, due to its relationship with seed index (Fig. 3 and Table 5). Regression coefficient (b=14.50) showed that a unit increase in seed index resulted into a proportional increase of 14.50 grams in seed cotton yield per plant. Ahmad *et al.* (2008) evaluated different *G. hirsutum* cultivars for yield and other economic characters and observed significant variations for seed traits and positive effect on yield and reported significant correlation, which indicated that any improvement in seed traits would have a positive effect on seed cotton yield.

Lint percentage (ginning outturn) is a complex polygenic trait which is largely affected by the environmental factors. Primarily, it depends on lint weight, which has the direct effect on seed cotton yield. Selection for higher ginning outturn often results in an increase in the production per plant and per unit area.

Taking a closer look at the results in Table 5, the coefficient of determination (R^2=0.48) revealed 48% of the total variation in seed cotton yield attributable to the variation in lint percentage (%). The regression coefficient (b=3.91) indicated that for a unit increase in lint percentage (%), there would be a proportional increase of 3.91 grams in seed cotton yield plant^{-1} (Fig. 4 and Table 5). However, the earliness index (%) showed non significant association with the seed cotton yield plant^{-1}.

The coefficient of correlation (r) and the coefficient of determination (R^2) values suggested that number of bolls plant^{-1}, boll weight, seed index and lint percentage (%) are the most important characters and can readily affect the seed cotton yield in a large extent. These traits are the major independent yield components and plays principal role and have a direct influence in management of seed cotton yield plant-1 . Thus variability for these traits among different cultivars is a good sign and selection in the breeding material for these traits will have a significant effect on the seed cotton yield. Our results are in conformity with those of Santoshkumar *et al.* (2012) who noted that number of bolls plant-1, boll weight, seed index and lint index have a significant positive association with seed cotton yield plant-1. These results are in line with the findings of Salahuddin *et al.* (2010).

From the above results of correlation and regression coefficients it can be concluded that selection for any character with a significantly positive association with seed cotton yield would improve the productivity of cotton crop.

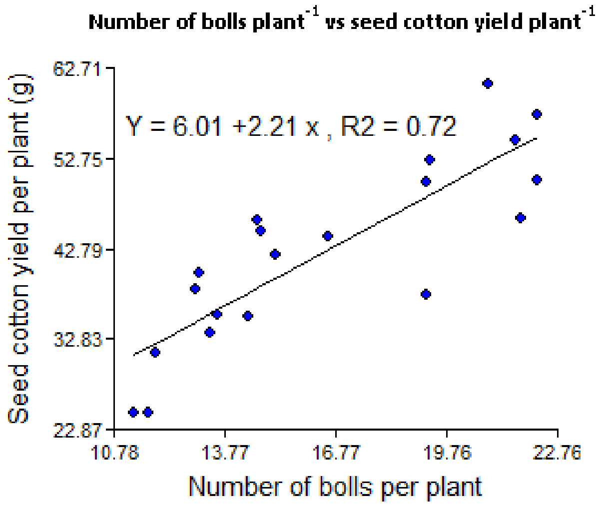

Fig. 1. Number of bolls plant-1

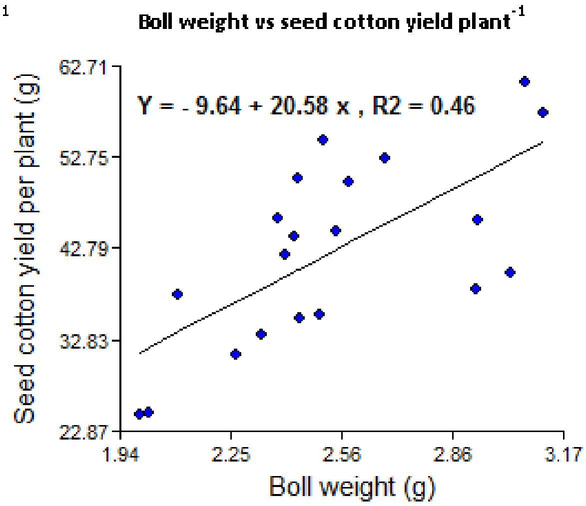

Fig. 2. Boll weight

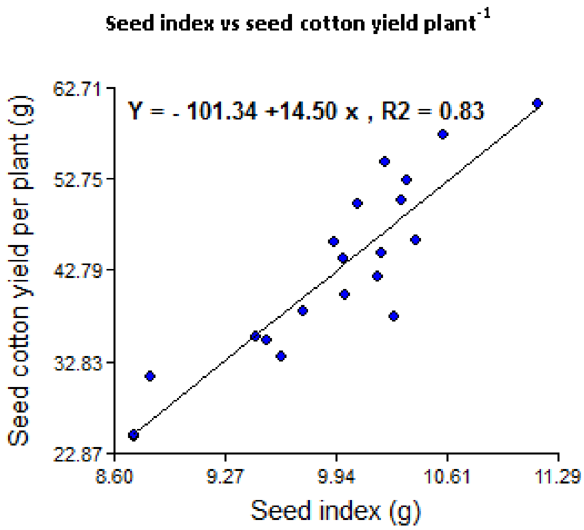

Fig. 3. Seed index

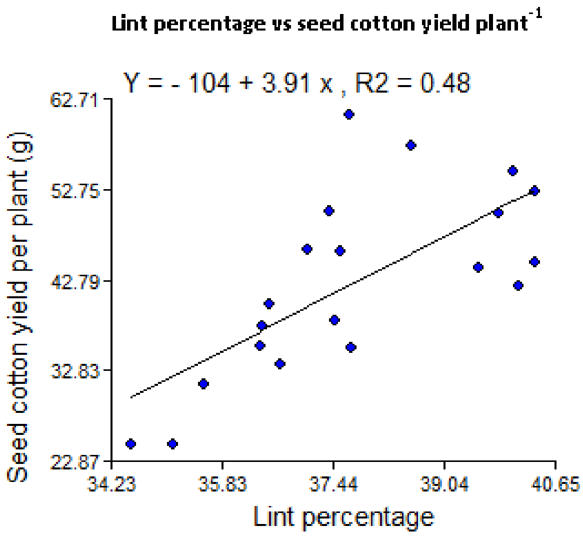

Fig. 4. Lint percentage

Fig. 1-4. Graphical presentation of functional relationship between yield components and seed cotton yield plant-1.

Path coefficient analysis

With respect to the complex relations of the traits with each other, the final judgment cannot be done on the basis of simple correlation and regression coefficients and as such, it is necessary to use multivariate statistical methods in order to intensely identify the reactions among the traits. In the meantime, path coefficients analysis is a method for the separation of correlation coefficients to their direct and indirect effects through other traits and it can provide useful information about affectability form of traits to each other and relationships between them.

Assuming seed cotton yield is a contribution of several characters which are correlated among themselves and to the seed cotton yield, path coefficient analysis was developed (Wright, 1921; Dewey and Lu, 1959). Unlike the correlation coefficient which measures the extent of relationship, path coefficient measures, the magnitude of direct and indirect contribution of a component character to a complex character and it has been defined as a standardized regression coefficient which splits the correlation coefficient into direct and indirect effects. Path coefficient analyses showing direct and indirect effect of some yield component traits on seed cotton yield per plant were given in Table 6. The direct, indirect and residual effects are shown by diagram given in Fig. 5.

Lenka and Mishra (1973) have suggested scales for path coefficients with values 0.00 to 0.09 as negligible, 0.10 to 0.19 low, 0.20 to 0.29 moderate, 0.30 to 0.99 high and more than 1.00 as very high path coefficients. Accordingly, in this study, the numbers of bolls per plant exhibited high positive direct effect (0.57).

Accordingly, in this study, the path coefficient analysis of different traits contributing towards seed cotton yield per plant revealed that the number of bolls plant^{-1} (0.57) had high positive direct effect followed by high positive direct effect of boll weight (0.39). However, the estimates were moderate for lint percentage (0.24), and negligible for seed index (0.06). While, earliness index (-0.01) expressed negligible negative direct effect on seed cotton yield per plant (Table 6). Present results are also in consonance with those obtained by Rauf *et al.* (2004) who observed that bolls plant^{-1} expressed maximum positive direct effect on seed cotton yield plant^{-1}.

The data presented in Table 6 reveals that the indirect effect of bolls per plant via boll weight was 0.11, through seed index was 0.05, through lint percentage 0.12 and by earliness index was in negative direction (- 0.001). From the results concerning path analysis it is evident that the indirect effect of boll weight through number of bolls plant^{-1} was 0.17. It was observed that although boll weight itself contributed significantly towards the final yield, nevertheless its major effect on seed cotton yield was through number of bolls per plant (Table 6 and Fig. 5).

From the results in Table 6 it was observed that the correlation between seed index and seed cotton yield per plant was positive and very high (0.91). It was observed that although the indirect effect of seed index through number of bolls plant^{-1} was positive and high 0.47, via boll weight was 0.23 and through lint percentage (%) was 0.15.

Besides, the residual effect (0.17) was high in magnitude which shows that some other important yield contributing characters are contributing to seed cotton yield and should be taken into consideration.

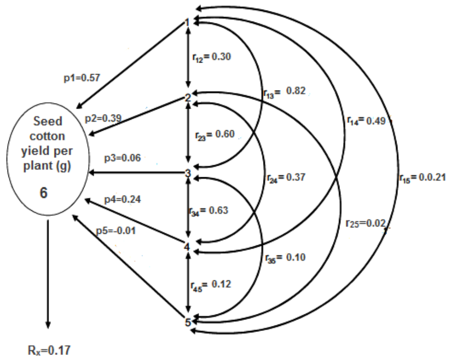

Fig. 5. Path diagram showing the relationship between seed cotton yield plant^{-1} and some yield components.

Key: One-directional arrow (→) represent direct path (p) and two-directional arrow (↔) represent correlations (r). 1- Number of bolls per plant, 2- Boll weight, 3- Seed index , 4- Lint percentage, 5- Earliness index, 6- Seed cotton yield plant^{-1}.

Table 6. Estimation of path coefficient analysis for some studied traits on the total yield.

Traits	Path coefficient values		Rate of scale
1- Effect of number of bolls plant^{-1} on seed cotton yield plant^{-1}:			
Direct effect	p1y	0.57	High
Indirect effect through boll weight	r12 p2y	0.11	Low
Indirect effect through seed index	r13 p3y	0.05	Negligible
Indirect effect through lint percentage (%)	r14 p4y	0.12	Low
Indirect effect through earliness index	r15 p5y	-0.001	Negligible
Sum of total effect	r1y	0.85	
2- Effect of boll weight on seed cotton yield plant^{-1}:			
Direct effect	p2y	0.39	High
Indirect effect through number of bolls plant^{-1}	r21 p1y	0.17	Low
Indirect effect through seed index	r23 p3y	0.04	Negligible
Indirect effect through lint percentage (%)	r24 p4y	0.09	Negligible
Indirect effect through earliness index	r25 p5y	0.0001	Negligible
Sum of total effect	r2y	0.68	
3- Effect of seed index on seed cotton yield plant^{-1}:			
Direct effect	p3y	0.06	Negligible
Indirect effect through number of bolls plant^{-1}	r31 p1y	0.47	High
Indirect effect through boll weight	r32 p2y	0.23	Moderate
Indirect effect through lint percentage (%)	r34 p4y	0.15	Low
Indirect effect through earliness index	r35 p5y	-0.0005	Negligible
Sum of total effect	r3y	0.91	
4- Effect of lint percentage (%) on seed cotton yield plant^{-1}:			
Direct effect	p4y	0.24	Moderate
Indirect effect through number of bolls plant^{-1}	r41 p1y	0.28	Moderate
Indirect effect through boll weight	r42 p2y	0.14	Low
Indirect effect through seed index	r43 p3y	0.04	Negligible
Indirect effect through earliness index	r45 p5y	-0.0007	Negligible
Sum of total effect	r4y	0.70	
5- Effect of earliness index on seed cotton yield plant^{-1}:			
Direct effect earliness index	p5y	-0.01	Negligible
Indirect effect through number of bolls plant^{-1}	r51 p1y	0.12	Low
Indirect effect through boll weight	r52 p2y	-0.01	Negligible
Indirect effect through seed index	r53 p3y	0.01	Negligible
Indirect effect through lint percentage (%)	r54 p4y	0.03	Negligible
Sum of total effect	r5y	0.14	
Residual effect = 0.17			

However, it was further clarified through the intensive investigation of path coefficient analysis that number of bolls plant^{-1} was the only yield component of major influence followed by boll weight and lint percentage which contributed substantially towards the final seed cotton yield. The results obtained also confirm the results reported by Mahdi (2014), Afiah and Ghoneim (2000), Soomro (2000) Gomaa *et al.* (1999).

Analysis of Stepwise multiple Regression

In order to remove effect of non-effective characteristics in regression model on grain yield, stepwise regression was used. In stepwise regression analysis, seed cotton yield plant^{-1}as dependent variable (Y) and other traits as independent variables were considered.

In multiple regression, the variance inflation factor (VIF) is used as an indicator of multicollinearity. Computationally, it is defined as the reciprocal of tolerance: 1 / (1 - R^2). All other things equal, researchers desire lower levels of VIF, as higher levels of VIF are known to affect adversely the results associated with a multiple regression analysis. Various recommendations for acceptable levels of VIF have been published in the literature. Perhaps most commonly, a value of 10 has been recommended as the maximum level of VIF (Hair *et al.*,1995; Neter and Kutner, 1989). On the basis of the results of processing various linear regression models, as shown in Table 7, indicated that the VIF of the traits varied from 1.2 to 1.4 and therefore in the acceptable levels of VIF.

Table 7. Relative contribution (partial and model R^2), regression coefficient (b), standard error (SE), t-value, variance inflation factor (VIF) and probability value (P) in predicting seed cotton yield by the stepwise procedure analysis.

Step	Variable entered	Partial R^2	Model R^2	b	SE	t	VIF	P-value
1	(x_1)	0.9645	0.9645	1.58	0.142	11.11	1.3	0.0001
2	(x_2)	0.0005	0.9650	12.35	1.553	7.95	1.2	0.0001
3	(x_4)	0.0001	0.9651	1.42	0.314	4.51	1.4	0.0004

Y= -68.33 + 1.58 number of bolls per plant + 12.35 boll weight + 1.42 lint percentage

Key note for Table 7: (x_1)= Number of bolls plant^{-1}, (x_2)= Boll weight (g), (x_4)= Lint percentage (%), Constant = -68.33 , R^2 =0.9651, R^2 (adjusted) = 0.9578.

Results of stepwise regression (Table 7) showed that the number of bolls per plant, boll weight and lint percentage with R square of 96.51%, had justified the maximum of yield changes. High value of the adjusted coefficient of determination (R^2 = 95.78%) indicates that the traits chosen for this study explained almost all seed cotton yield variation. Considering that the number of bolls per plant was (x_1), boll weight (x_2) and lint percentage (x_4), therefore by using multiple linear regression model, we estimated regression equation and defined regression coefficients and the following equation can be obtained:

Y= -68.33+1.58 number of bolls plant^{-1}+ 12.35 boll weight+1.42 lint percentage

Keeping in view the existence of significant R square in a successful regression equation indicates the effectiveness of these traits to increase seed cotton yield plant^{-1}. Above equation showed that the number of bolls plant^{-1}, boll weight and lint percentage had most positive influence on seed cotton yield^{-1} .

From the previous model, it is deduced that for every unit increase in number of bolls plant^{-1} there is a increase of 1.58 grams of seed cotton yield plant^{-1} and a increase of about 12.35 grams of the seed cotton yield plant^{-1} was observed when the boll weight is increased by one unit. Similarly, an increase of about 1.42 grams of seed cotton yield plant^{-1} was noted for every unit increase in lint percentage (%). The plant breeder would thus have available information which would enable him to determine for which yield component characters he should select in order to maximize yield.

Factor analysis

Factor analysis is a powerful multivariate statistical technique that it is used to identify the effective hidden factors on the seed cotton yield. El-Badawy (2006) found that using factor analysis by plant breeders has the potential of increasing the comprehension of causal relationships of variables and can help to determine the nature and sequence of traits to be selected in breeding programs.

Factor analysis is an effective statistical method in decreasing the volume of the data and getting the results of the data which showed a high correlation among the primary variables (Cooper, 1983). Selecting factor numbers was done on the basis of root numbers larger than 1 and the number of the primary variables used in the factor analysis was equal to 5. According to the formula $F < (P+1)/2$ (in which P and F refer to the number of variables and number of factors, respectively), selection of two factors was compatible with the presented principles (Tousi Mojarrad *et al.,* 2005). This method was used effectively for identifying the relationships and structure of yield components and some traits of cultivated plants (Bramel *et al.,* 1984; Walton, 1971).

Factor analysis is a method that in more number of correlated variables decreased into smaller groups of variables which called a factor. Before doing of the factor analysis the suitability of data for factor analysis was determined by data adequacy test (KMO) and Bartlett sphericity test (Hair *et al.,* 2006).

The KMO measure of sampling adequacy of data was 67% and Bartlett's test was significant at the one percent level (Table 8) which showed existing correlations among data are suitable for factor analysis.

Table 8. KMO and Bartlett's test of variables.

Kaiser -Meyer-Olkin (KMO Measure of Sampling Adequacy.	0.673
Bartlett's Test of Sphericity Approx. Chi-Square.	38.671
Degrees of freedom	10
The significance level	0.0001

In order to identify vital components that contribute to total variation, factor analysis was conducted. Table 9 shows total variance of each factor in percentage, which shows its importance in interpretation of total variation of data. The total variance explained by factors is indicated in Table 9, only the first 2 factors, which account for 73.96% of the total variance, are important. Therefore, the contribution of each trait according to other traits is obtained. Two classes of independent factors were chosen based on Eigen values >1, which together compose 73.96% of total variation. Validity of the factor selection was confirmed by Scree graph (Fig. 6).

The scree plot graphs the Eigenvalue against the each factor. We can see from the graph that after factor 2 there is a sharp change in the curvature of the scree plot. This shows that after factor 2 the total variance accounts for smaller and smaller amounts.

Table 9. Total variance explained for each factor based on 5 different characters of 20 Egyptian cotton genotypes.

Factor	Eigen values	% of variance	Cumulative %
Number of bolls per plant	2.660	53.209	53.209
Boll weight (g)	1.038	20.752	73.961
Seed index (g)	0.666	13.322	87.282
Lint percentage (%)	0.539	10.781	98.063
Earliness index (%)	0.097	1.937	100.000

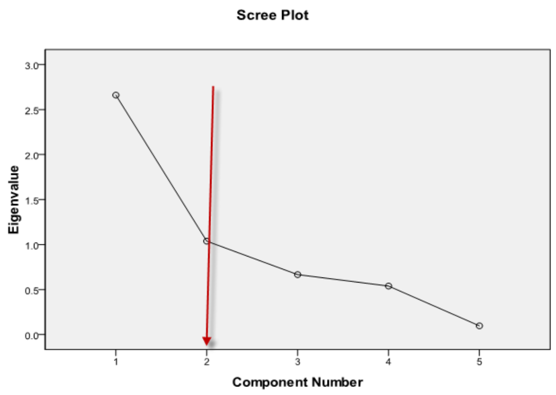

Fig. 6. Scree plot showing eigen values in response to number of components for the estimated variables of cotton.

A principal factor matrix after orthogonal rotation for these 2 factors is given in (Table 10). The values in the table, or loadings, indicate the contribution of each variable to the factors. For the purposes of interpretation only, those factor loadings greater than 0.5 were considered important, these values are highly lighted in bold in Table 10.

In factor analysis of 5 traits, Factor 1, which accounted for about 53% of the variation, was strongly associated with number of bolls plant^{-1}, boll weight (g), seed index (g) and lint percentage (%) in the linear combination of the first factor. This factor was regarded as productivity per plant factor since it included several traits which are components of yield. These variables had positive loadings in factor 1. The sign of the loading indicates the direction of the relationship between the factor and the variable. The second factor (Factor 2) was strongly associated with earliness index (%) only, which accounts for about 21% of the total variation and had the most positive linear combination coefficients of the second factor. Similar results were obtained by Alishah *et al.* (2008) who stated that factor analysis classified the fourteen cotton variables into four main groups which accounted for 83.58% of the total variability in the dependence structure. El-Kady *et al.* (2015) who found that two factors accounted for 83.57% of variation among traits in some Egyptian cotton cultivars.

Table 10. Principal factor matrix after varimax rotation for 5 characters of 20 genotypes of Egyptian cotton.

Variables	Factors		Communality
	Factor 1	Factor 2	
Number of bolls per plant	0.800	0.297	0.815
Boll weight (g)	0.710	0.173	0.744
Seed index (g)	0.953	-0.201	0.629
Lint percentage (%)	0.755	0.107	0.770
Earliness index (%)	-0.120	0.942	0.296
Latent roots	2.625	1.073	3.698
Factor variance (%)	53.209	20.752	73.961

Key note for Table 10: Numbers in bold are those with factor loadings greater than 0.50.

Communality values of factor analysis for the measured traits of Egyptian cotton are given in Table 10 and results indicated that number of bolls plant^{-1}, boll weight, seed index and lint percentage traits had the highest communality and consequently the high relative contribution in seed cotton yield.

The findings of the study concluded that, on the basis of the multiple statistical procedures which have been used in this study showed that number of bolls plant^{-1} (x_1), boll weight (x_2) and lint percentage (x_4) were the most important yield variables to be considered for these cultivars. These procedures were shown in Table (11) for all studies variables. Thus, high yield of cotton plants based on these cultivars can possibly be obtained by selecting breeding materials with high values of these traits.

Table 11. Cotton traits identified as crucial in grain yield with each one of the used statistical techniques.

Traits	*Statistical procedures*					Total score
	Simple correlation	Simple regression	Path analysis	Stepwise regression	Factor analysis	
Number of bolls plant^{-1}	√	√	√	√	√	5
Boll weight (g)	√	√	√	√	√	5
Seed index (g)	√	√			√	3
Lint percentage (%)	√	√	√	√	√	5
Earliness index (%)					√	1

Conclusion

In general, the following major findings can be summarized from this study:

- In conclusion, correlation coefficient analysis measures the magnitude of relationship between various plant characters and determines the component character on which selection can be based for improvement in seed cotton yield. However, path coefficient analysis helps to determine the direct effect of traits and their indirect effects on seed cotton yield. Number of bolls plant^{-1}, boll weight and lint percentage had major contributions on seed cotton yield and hence selection for these traits can possibly lead to improvement in seed cotton yield of Egyptian cotton.

- Results of the study showed that these genotypes may provide good source of material for further breeding program. The multiple statistical procedures which have been used in this study showed that simple correlation and regression analysis cannot distinguish important variables affecting seed cotton yield, the final judgment cannot be done on the basis of these methods as such, it is necessary to use multivariate statistical methods in breeding programs for screening important traits in cotton crop. Information from this study would be valuable to cotton breeder for developing high yielding cultivars for seed cotton yield.

- The results of this research could be implemented for improving productivity of cotton crop. Last but not least the present investigation provided considerable information that could be useful for cotton breeders, statisticians and agronomists to understand the nature of the relationship between the most important factors affecting the yield of cotton.

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