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ORIGINAL RESEARCH

Analysis of Genetic Diversity, Correlation, and Phenotypic Path Coefficients in Hybrids of Kenaf (*Hibiscus Cannabinus* L.) Cultivated for High Fibre Yield

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ABSTRACT: Kenaf is an economically important fiber crop globally for multipurpose industrial uses such as paper making, interior car components and building boards. Correlation and path coefficient analysis help breeders create breeding procedures that maximize yield through selection by assisting in the understanding of trait interactions. To develop selection criteria for high fibre yield, this research examined the direct and indirect effects of yield and yield-related traits among 36 kenaf hybrids. The pooled analysis of variance over two seasons showed highly significant differences among genotypes and genotype-by-season interaction for all traits except for stem top diameter and plant height. The fibre weight substantially correlated with seven traits at both the phenotypic and genotypic levels. Hence, selection based on these traits will effectively increase kenaf fibre yield. The path coefficient analysis revealed the maximum contribution of core diameter to fibre yield followed by fresh stem weight without leaves and pod. The first five principal component analyses (PCA) accounted for 91.8% variation between genotypes based on a correlation matrix of all the quantitative traits. For the development of kenaf varieties with acceptable yield, effective selection can be based on stem base diameter, stem middle diameter, core diameter, nodes number, stick weight, fresh stem weight with leaves and pod, and fresh stem weight without leaves and pod.

KEYWORDS: Correlation, path coefficient, direct effect, heritability, kenaf mutants.

1. Introduction

Kenaf is a multipurpose crop that provides biomass and natural fibre for industrial purposes, owing to its height growth and fibre content (Al-Mamun et al., 2023). To assist successful selection, the extent and level of genetic variability present within a plant population must be determined, eventually leading to the identification and implementation of novel enhanced and superior genotypes from that population (Usman et al., 2014). Hence, this study aimed to investigate the genetic components of genetic variability in kenaf hybrids, estimate heritability and genetic advance between various yield components and find correlations between yield and yield-related traits to help breeders use those traits for breeding. To estimate a trait's breeding value, phenotypic reliability and genetic control over its expression are demonstrated via heritability (Ene et al., 2016; Onwubiko et al., 2019).

Mutation breeding is a form of conventional plant breeding that comprises physical or chemical mutagenesis to determine the genetic variability that will improve varieties with superior traits (Oladosu et al., 2016). The process of crop improvement through induced mutagenesis has been a well-known plant breeding approach that immensely contributed to the genetic variability and yield improvement in numerous crops. Analysis revealed many significant interrelationships between morphological traits, yield and yield components of estimated fibre yield. Yield components were selected as second-order traits as they would have higher direct effects on fibre yield. In contrast, morphological parameters were chosen in the first order to assess their influence on the second-order components.

Genetic correlations are caused by genetic factors and provide information about the additive relationship between two traits, which is critical for effective selection. Phenotypic correlations are caused by environmental and genetic factors and can be distinguished by measuring the phenotype (Elgart et al., 2022). There is a significant positive correlation between the two characters because of their strong relationship, indicating that they can be improved simultaneously in a selection program (Schober et al., 2018). Fibre yield correlations are used to determine mutual associations rather than relationships. The correlation coefficient is divided into direct and indirect causes of association using the path coefficient analysis, revealing how much a trait contributes to yield (Jakhar et al., 2017). Path coefficient analysis deals with several interrelated variables in a model. This technique was first developed by Sewall Wright in the 1920s to analyze independent factors' direct and indirect effects on the dependent variables (Bondari, 1990). Path coefficient, also known as standardized partial regression coefficient, is calculated from correlations, whereas path regression coefficients are not. In such cases, Alemu et al. (2014) suggested that indirect and direct effects should be considered simultaneously in selection programs. Path analysis goes further, indicating the causes and determining the importance of each character to produce results by dividing correlation coefficients into components of direct and indirect causes of association (Olawamide et al., 2020).

Furthermore, correlated response and relative selection efficiency help to understand the expected rate of genetic improvement through indirect selection and path analysis helps in determining yield contributing characters (Islam et al., 2004). Thus, correlation estimation and path analysis provide a clear picture of the relationship between two characters and partition the relationship into direct and indirect effects, indicating the relative contribution of each causal factor to the yield (Pervin & Haque, 2012). Using path coefficient analysis, variation in correlation analysis was analyzed to identify whether the half-diallel cross types possessed different mechanisms or pathways to produce fibre yield.

Yield is inherited quantitatively and influenced by both genetic and environmental factors. However, the genetic characteristic of kenaf is still poorly understood due to the influence of the environment on flowering and fiber yield in Malaysia (Al-Mamun et al., 2020). Fibre yield is a complex trait influenced by various independent traits, and improving it requires a thorough understanding of their interrelationships. As a result, investigations of the relationship between features and their direct and indirect effects on yield are significant because they aid in selecting desirable qualities. Hence, the present study was designed to determine heritability and correlations across features and analyze interactions among kenaf hybrids based on fibre yield component attributes.

2. Materials and methods

2.1 Plant husbandry

Nine kenaf genotype parents were used as parents in 9 × 9 half-diallel crosses to create 36 F_1 hybrids in this study. Among the nine genotypes, eight mutant lines were developed from V-36 through acute and chronic gamma irradiation by the Malaysian Nuclear Agency in Bangi, Selangor, and one was a commercial variety (BJRI kenaf4) from Bangladesh. The eight mutant lines consist of six M_6 and two M_7 lines.

2.2 Experimental location

The parents were diallel mating in all possible combinations, barring reciprocals at Field 10 at University Putra Malaysia from February to May 2020. The field evaluation was repeatedly carried out in a humid tropical climate over two seasons, the first from June to September 2020 and the second from March to June 2021.

2.3 Experimental design and field layout

The land was mechanically ploughed for plant culture, then laddered by standard kenaf production to generate a good crop under optimal management. In a randomized complete block design with three replications, seeds of 36 F_1s were hand-planted to a depth of 2 - 2.5 cm in a plot size of 60 × 10 m^2 with row spacing of 10 × 40 cm^2. After 40 days of planting, the appropriate dose of fertilizers NPK Green (15:15:15) and NPK Blue (12:12:17) was sprayed, as specified by Wong et al. (2008). Intercultural operations such as weeding, thinning, supplemental irrigations, and plant protection measures were carried out at the proper time throughout the cropping season.

2.4 Data collection

Data were collected on twelve agro-morphological traits from 10 random plants for each genotype per replication. Quantitative data collected include Core diameter, Nodes number, Days to first flowering, Days to 50% flowering, Stick weight, Plant height, Stem base diameter, Stem middle diameter, Stem top diameter, Fresh stem weight with leaves and pod, Fresh stem weight without leaves and pod, and Fibre weight.

2.5 Statistical analysis

2.5.1. Phenotypic and genotypic coefficients of variation

The estimates of phenotypic and genotypic coefficients of variation were calculated using the following formula proposed by Singh and Chaudhary (1977) as follows:

$$PCV(\%) = \sqrt{\sigma^2_p} / \bar{x} \times 100$$

$$GCV(\%) = \sqrt{\sigma^2_g} / \bar{x} \times 100$$

Where σ^2p denotes phenotypic variance, σ^2g denotes genotypic variance, and $\bar{x}$ indicates the mean of the trait. According to Sivasubramanian and Madhava (1973), GCV and PCV values were classified as high (20% and above), moderate (10-20%) and low (0-10%) values.

2.5.2. Heritability estimate

The formula proposed by Falconer (1996) was used to calculate broad-sense heritability (h^2_B), which is the ratio of genotypic variance (σ^2g) to the phenotypic variance (σ^2p).

$$h^2_B(\%) = \frac{\sigma^2_g}{\sigma^2_p} \times 100$$

Where σ^2g represents genotypic variance and σ^2p represents phenotypic variance. The value of heritability (h^2) estimate was defined as low if it was less than 20%, moderate if it was between 20% and 50%, and high if it was more than 50% (McWhirter et al., 1979).

2.5.3. Genetic advance

The genetic advance (GA) was calculated using the method of Assefa et al. (1999), with selection intensity (K) assumed to be 5%.

$$GA\% = K \times \frac{\sqrt{\sigma^2_p}}{x} \times h^2_B \times 100$$

Where K is the selection intensity constant, when K is 20%, the value is 1.40, $\frac{\sqrt{\sigma^2_p}}{x}$ represents the phenotypic standard deviation, h^2_B represents heritability and $\bar{x}$ represents the mean of the traits. According to Johnson et al. (1955), genetic advance was classified as low (0-10%), moderate (10-20%), and high (>20%).

2.5.4 Multivariate analysis

Using NTSYS-pc 2.2 software ((Numerical Taxonomy Multivariate Analysis System), Exeter Software (NTSYS-pc, N. T., 2005), Setauket, NY, USA software, principal component analysis (PCA) was done to produce multivariate statistical analysis (MVSA) such as PCA biplot loading.

2.5.5 Correlation analysis

All traits measured in the trial were analyzed using Pearson's correlation coefficients. Means of individual plots for each trait were used in the analysis using PROC CORR in SAS to investigate any possible relationship between traits at an alpha value of 0.05. A coefficient value of 0 indicates the absence of any association between variables, a positive value indicates a positive relationship, and a negative value indicates a negative relationship. A value close to zero, either positive or negative, showed a weak correlation, whereas a value nearing either 1 or -1 indicated a strong correlation (Benesty et al., 2009).

2.5.6 Genotypic and phenotypic correlation coefficients

Estimates of genotypic and phenotypic correlation coefficients were made using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Kashiani and Saleh (2010) described the genotypic and phenotypic levels for determining the association among several characters and yield per hectare. Phenotypic correlations were then further divided into direct and indirect effects components using methods described by Wright (1921) for path coefficient analysis. Path coefficients were calculated using Usman et al. (2017) guidelines. Relationships between correlations and path coefficients were revealed using a matrix containing simultaneous equations. These equations, as listed below, consist of phenotypic correlation values between variables (r), direct effects of one variable on another (P) and indirect effects from multiple variables (rijPij). Path coefficient analysis was carried out for each cross type and general relationships across the cross-types. Serial numbers defining each variable are as follows:

The first-order components are 1 - Core diameter (CD), 2 - Nodes number (NN), 3 - Days to first flowering (DTFF), 4 - Days to 50% flowering (D50%F) and 5 - Stick weight (SW). The second-order components are 6 - Plant height (PH), 7 - Stem base diameter (SBD), 8 - Stem middle diameter (SMD), 9 – Stem top diameter (STD), 10 - Fresh stem weight with leaves and pod (FSW1), and 11 - Fresh stem weight without leaves and pod (FSW2). Second-order and first-order components were used to divide the characters under investigation further. The cause and effect relationships between the two components were calculated using simultaneous equations in matrix notation. Path coefficient analysis was carried out using a different population to assess the contribution of vegetative traits to fibre yields. This analysis would include progenies of varied vegetative appearance and a range of estimated yields to draw accurate correlation and path coefficients.

3. Results

3.1 Genetic analysis, broad-sense heritability and genetic advance

The genotypic (g) and phenotypic (p) variance estimations varied from 0.01 to 111532.28 and 1.47 to 179902.40, respectively (Table 1). Stick weight, plant height, fresh stem weight with leaves and pods, fresh stem weight without leaves and pods, and fibre weight were all phenotypic and genotypic variations. There is little genotypic and phenotypic variation in node number, stem middle diameter, and stem top diameter. GCV and PCV estimations varied from 1.89% to 25.60% and 10.69% to 32.51%. Fresh stem weight with leaves and pods had the greatest PCV (32.51%), followed by stick weight (30.60%), stem top diameter (28.03%), fresh stem weight without leaves and pods (27.36%), fibre weight (25.97%), and nodes number (25.27%). Fresh stem weight with leaves and pods (25.60%) had the highest GCV, followed by fibre weight (20.79%), showing considerable genotypic variability in these traits and the possibility for additional selection.

Combined data from the two environments and broad-sense heritability estimates for qualities measured on the 36 kenaf hybrids created from a 9 × 9 half-diallel cross (Table 1). Broad-sense heritability in this study ranged from 0.68% (stem top diameter) to 64.04% (fibre weight). Fibre weight was the most heritable trait, with a broad-sense heritability of 64.04%, followed by fresh stem weight with leaves and pod (62%), the only two factors that demonstrated significant heritability (>60%), according to the combined data from the two environments. Stem base diameter (56.61), core diameter (53.61), days to first flowering (50.19), nodes number (40.58), plant height (39.38), and stick weight (32.90) all showed moderate heritability (30 - 60%). Khatun (2007) found similar results for *C. capsularis* as well. The remaining variables, such as days to 50% flowering, stem middle diameter, and stem top diameter, had poor broad-sense heritability, indicating that non-additive gene effects predominated in trait inheritance. Fresh stem weight with leaves and pods had the most significant genetic advance (52.74%), followed by fibre weight (42.82%),

Table 1. Means squares of variation of 12 quantitative traits of 36 hybrids over two seasons.

Traits	Mean	σ^2g	σ^2p	GCV (%)	PCV (%)	RD (%)	h^2_B (%)	GA (%)
CD	22.84	9.59	17.89	13.56	18.52	26.79	53.61	27.93
NN	7.73	1.55	3.82	16.09	25.27	36.34	40.58	33.14
DTFF	50.03	14.35	28.59	7.57	10.69	29.16	50.19	15.60
D50%F	58.32	12.20	49.80	5.99	12.10	50.50	24.50	12.34
SW	112.49	389.77	1184.67	17.55	30.60	42.64	32.90	36.15
PH	269.71	406.05	1031.07	7.47	11.91	37.25	39.38	15.39
SBD	26.47	10.66	18.83	12.33	16.39	24.76	56.61	25.41
SMD	12.11	1.21	4.70	9.07	17.90	49.31	25.74	18.69
STD	4.32	0.01	1.47	1.89	28.03	93.26	0.68	3.89
FSW1	1304.52	111532.28	179902.40	25.60	32.51	21.26	62.00	52.74
FSW2	337.67	4076.08	8536.05	18.91	27.36	30.90	47.75	38.95
FW	26.19	29.64	46.28	20.79	25.97	19.97	64.04	42.82

Note: σ^2g, Genotypic variation; σ^2p, Phenotypic variation; GCV, Genotypic coefficient variation; PCV, Phenotypic coefficient variation; RD, Relative differences; h^2_B, Broad-sense heritability; GA, Genetic advance; CD, Core diameter; NN, Nodes number; DTFF, Days to first flowering; D50%F, Days to 50% flowering; SW, Stick weight; PH, Plant height; SBD, Stem base diameter; SMD, Stem middle diameter; STD, Stem top diameter; FSW1, Fresh stem weight with leaves and pod; FSW2, Fresh stem weight without leaves and pod, and FW, Fibre weight.

and stem top diameter had the lowest (3.89%).

In the case of a specific trait, high heritability indicates a strong similarity between offspring. Generally, fibre and fresh stem weights with leaves and pod had consistently high broad-sense heritability values in the combined data from both environments. This is attributable to the fact that genetic impacts control traits more than environmental effects. Due to the limited impact of the environment on the phenotypes, broad-sense heritability estimates for yield traits evaluated in the combined data of the two environments were high (>60%), showing a close connection between genotypes and phenotypes.

3.2 Valuation of principal component analysis

Based on the results from Table 2, it appeared that the principal component 1 (PC1) accounted for 51.19% of the total variation, and the characters responsible for genotypes separation along this axis were stem base diameter, core diameter, fresh stem weight without leaves and pod, fresh stem weight with leaves and pod, stick weight, fibre weight, stem middle diameter, nodes number, plant height, and stem top diameter with a high and positive value of the coefficient of variation. Days to 1st flowering (maximum 0.569), days to 50% flowering, nodes number, core diameter, stem base diameter, and fibre weight made up the second principal component (PC2), which accounted for 22.02% variation. Principal Component 3 (PC3) accounted for 8.83%

Table 2. Eigenvectors and values for the first five principal component axes for 12 agronomic traits associated with kenaf hybrids.

Eigenvectors					
Characters	PC1	PC2	PC3	PC4	PC5
Eigenvalue	6.14	2.64	1.06	0.70	0.47
Proportion of Variance (%)	51.19	22.02	8.83	5.87	3.91
Cumulative Proportion of Variance (%)	51.19	73.21	82.04	87.91	91.8
Core diameter	0.385	0.108	-0.017	0.024	-0.076
Nodes number	0.238	0.279	-0.056	-0.734	0.174
Days to 1st flowering	-0.001	0.569	0.075	0.281	0.262
Days to 50% flowering	-0.042	0.555	0.218	0.052	0.319
Stick weight	0.337	-0.140	-0.114	0.229	0.067
Plant height	0.210	-0.400	0.027	0.139	0.720
Stem base diameter	0.388	0.103	-0.012	0.047	-0.058
Stem middle diameter	0.319	-0.165	0.283	-0.217	0.258
Stem top diameter	0.110	-0.082	0.899	0.061	-0.260
Fresh stem weight with leaves and pod	0.351	-0.041	-0.096	-0.279	-0.275
Fresh stem weight without leaves and pod	0.370	0.020	-0.116	0.367	-0.089
Fibre weight	0.334	0.228	-0.139	0.205	-0.224

variation and showed differences in days to 50% flowering, stem middle diameter, and stem top diameter (largest 0.472). The traits of days to 1st flowering, stick weight, plant height, fresh stem weight without leaves and pod (maximum 0.367), and fibre weight made up the principal component 4 (PC4), which accounted for 5.87% variation. The variance (3.91%) was observed for the last principal component 5 (PC5), which included days to first flowering, days to 50% flowering, nodes number, plant height (maximum 0.720), and stem middle diameter up to this principal component covered about % of the cumulative variation. The proportion of variation for principal components (PC1) and (PC2) were 51.19% and 22.02%, respectively, with the first principal component accounting for the majority of the total variation (Table 2).

3.3 Correlation among morpho-physiological traits

Ratner (2009) provides a widely accepted method for interpreting correlation coefficients. This study clarifies the phenotypic and genotypic correlation coefficients of yield and yield components. As shown in Table 3, the SAS software version 9.4 program proc corr calculates R-values and performs a significance test. The R-value for Karl Pearson's correlation coefficient does not measure the magnitude of the relationship, but it does give an indication. Most traits don't exist in isolation,

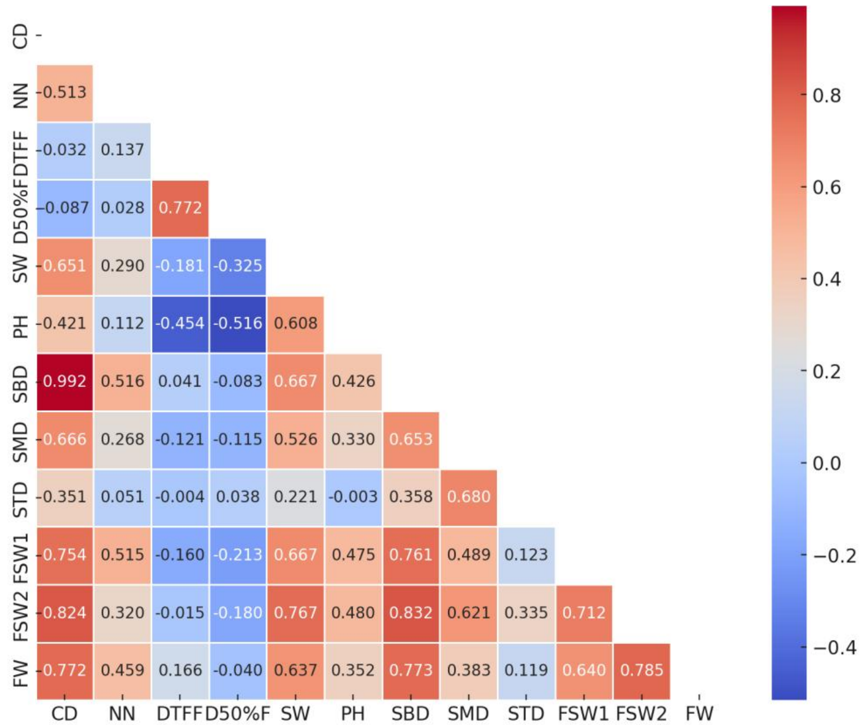

Figure 1. Genotypic correlation coefficient (rg) (below diagonal) and phenotypic correlation coefficient (rp) (upper diagonal) of 12 traits of 36 kenaf hybrids Note: CD, Core diameter; NN, Nodes number; DTFF, Days to first flowering; D50%F, Days to 50% flowering; SW, Stick weight; PH, Plant height; SBD, Stem base diameter; SMD, Stem middle diameter; STD, Stem top diameter; FSW1, Fresh stem weight with leaves and pod; FSW2, Fresh stem weight without leaves and pod, and FW, Fibre weight.

rather it is an association with one another which forms a complex relationship that ultimately influences the yield. This association could either be positive or negative. The correlation coefficient R-value shows the relationship between two distinct traits by identifying an association. The R-values of -1, 0, and +1 indicate perfect negative, no linear, and perfect positive relationships. The values that range from -0.7 to -1, -0.3 to -0.7 and 0 to -0.3 indicate strong, moderate, and low negative linear relationships, respectively. In contrast, the values ranging from 0.7 to 1, 0.3 to 0.7, and 0 to 0.3 indicate strong, moderate, and low positive linear relationships, respectively Oladosu et al. (2018).

Phenotypic character correlation coefficients range from -0.003 to 0.992, while genotypic character correlation coefficients range from -0.008 to 0.933. This indicates that the genotypic level is more significant in most cases than the phenotypic levels, implying that environmental effects were eliminated, resulting in a stronger genetic association. Fresh stem weight without leaves and pod (0.785), Stem base diameter (0.773), core diameter (0.772), fresh stem weight with leaves and pod (0.640),

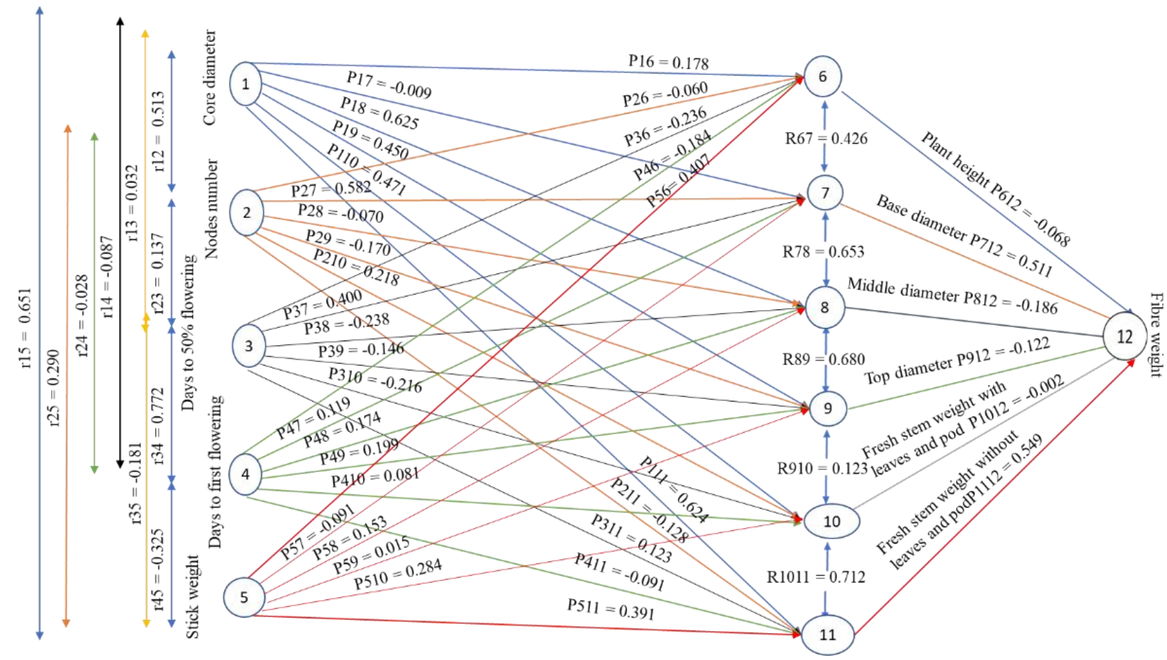

Figure 1. The influence of first-order on second-order components and the latter on yield is depicted in a genotypic path diagram with coefficients of factors (the direct effects are represented by pij values, while rij values represent the correlation coefficients).

Table 4. Phenotypic path analysis on the direct (diagonal) and indirect effects of eleven traits on fibre yield in 36 kenaf hybrids.

Traits	CD	NN	DTFF	D50%F	SW	PH	SBD	SMD	STD	FSW1	FSW2
CD	**0.723**	0.371	0.023	-0.063	0.470	0.304	0.717	0.482	0.253	0.545	0.596
NN	0.056	**0.109**	0.015	0.003	0.032	0.012	0.056	0.029	0.006	0.056	0.035
DTFF	0.005	0.023	**0.167**	0.129	-0.030	-0.076	0.007	-0.020	-0.001	-0.027	-0.003
D50%F	0.003	-0.001	-0.024	**-0.031**	0.010	0.016	0.003	0.004	-0.001	0.007	0.006
SW	0.096	0.043	-0.027	-0.048	**0.148**	0.090	0.099	0.078	0.033	0.098	0.113
PH	-0.003	-0.001	0.003	0.003	-0.004	**-0.007**	-0.003	-0.002	0.000	-0.003	-0.003
SBD	-0.329	-0.171	-0.013	0.027	-0.222	-0.142	**-0.332**	-0.217	-0.119	-0.253	-0.276
SMD	-0.150	-0.060	0.027	0.026	-0.119	-0.074	-0.147	**-0.225**	-0.153	-0.110	-0.140
STD	-0.021	-0.003	0.000	-0.002	-0.013	0.000	-0.021	-0.041	**-0.060**	-0.007	-0.020
FSW1	-0.008	-0.006	0.002	0.002	-0.007	-0.005	-0.008	-0.005	-0.001	**-0.011**	-0.008
FSW2	0.400	0.155	-0.007	-0.088	0.372	0.233	0.404	0.301	0.162	0.345	**0.485**
FW	0.771^{**}	0.459^{**}	0.166	-0.040	0.637^{**}	0.351^{**}	0.773^{**}	0.383^{**}	0.119	0.640^{**}	0.785^{**}

Note: CD, Core diameter; NN, Nodes number; DTFF, Days to first flowering; D50%F, Days to 50% flowering; SW, Stick weight; PH, Plant height; SBD, Stem base diameter; SMD, Stem middle diameter; STD, Stem top diameter; FSW1, Fresh stem weight with leaves and pod; FSW2, Fresh stem weight without leaves and pod, and FW, Fibre weight.

Table 5. First-order and second-order relationships.

	Variable	CD	NN	DTFF	D50%F	SW
Plant height (PH)	CD	**0.178**	0.091	0.006	-0.015	0.116
	NN	-0.031	**-0.060**	-0.008	-0.002	-0.017
	DTFF	-0.008	-0.032	**-0.236**	-0.182	0.043
	D50%F	0.016	-0.005	-0.142	**-0.184**	0.060
	SW	0.265	0.118	-0.074	-0.132	**0.407**
	PH	0.421**	0.112	-0.454**	-0.516**	0.608**
Stem base diameter (SBD)	CD	**-0.009**	-0.006	0.003	-0.004	0.000
	NN	0.383	**0.582**	-0.038	0.313	0.162
	DTFF	-0.153	-0.026	**0.400**	-0.028	0.152
	D50%F	0.046	0.064	-0.008	**0.119**	0.026
	SW	-0.231	-0.336	0.023	-0.182	**-0.091**
	SBD	0.036	0.278*	0.380*	0.218	0.248*
Stem middle diameter (SMD)	CD	**0.625**	0.321	0.020	-0.054	0.407
	NN	-0.036	**-0.070**	-0.010	-0.002	-0.020
	DTFF	-0.008	-0.033	**-0.238**	-0.184	0.043
	D50%F	-0.015	0.005	0.135	**0.174**	-0.057
	SW	0.100	0.044	-0.028	-0.050	**0.153**
	SMD	0.666**	0.268*	-0.121	-0.115	0.526**
Stem top diameter (STD)	CD	**0.450**	0.231	0.014	-0.039	0.293
	NN	-0.087	**-0.170**	-0.023	-0.005	-0.049
	DTFF	-0.005	-0.020	**-0.146**	-0.113	0.026
	D50%F	-0.017	0.006	0.154	**0.199**	-0.065
	SW	0.010	0.004	-0.003	-0.005	**0.015**
	STD	0.351**	0.051	-0.004	0.038	0.221*
Fresh stem weight with leaves and pod (FSW1)	CD	**0.471**	0.242	0.015	-0.041	0.306
	NN	0.112	**0.218**	0.030	0.006	0.063
	DTFF	-0.007	-0.030	**-0.216**	-0.167	0.039
	D50%F	-0.007	0.002	0.063	**0.081**	-0.026
	SW	0.185	0.082	-0.051	-0.092	**0.284**
	FSW1	0.754**	0.515**	-0.160	-0.213*	0.667**
Fresh stem weight without leaves and pod (FSW2)	CD	**0.624**	0.320	0.020	-0.054	0.406
	NN	-0.066	**-0.128**	-0.018	-0.004	-0.037
	DTFF	0.004	0.017	**0.123**	0.095	-0.022
	D50%F	0.008	-0.003	-0.070	**-0.091**	0.030
	SW	0.254	0.113	-0.071	-0.127	**0.391**
	FSW2	0.824**	0.320**	-0.015	-0.180	0.767**

Note: CD: Core diameter; NN: Nodes number; DTFF: Days to first flowering; D50%F: Days to 50% flowering; SW: Stick weight.

stick weight (0.637), nodes number (0.459), stem middle diameter (0.383) and plant height (0.352) with fibre weight had highly significant and positive phenotypic correlations. At the genotypic correlations, the fibre weight was significantly and positively correlated with fresh stem weight without leaves and pod (0.922), core diameter (0.912), Stem base diameter (0.901), stick weight (0.807), fresh stem weight with leaves and pod (0.657), nodes number (0.596), and stem middle diameter (0.546). Khatun et al. (2007) made correlation and regression studies in white jute and found a strong and positive correlation between fibre yield and its components, viz., plant height, stem base diameter, green weight and stripped weight. Days to first flowering and days to 50% flowering were highly positively correlated with each other, and this finding was also supported by Golam et al. (2011), who reported a high positive correlation between days of flowering and days of maturity, as well as a negative correlation with most of the other traits including fibre weight.

At the phenotypic and genotypic levels, the fibre weight was significantly and positively correlated with core diameter, nodes number, stick weight, stem base diameter, stem middle diameter, fresh stem weight with leaves and pod, and fresh stem weight without leaves and pod. Selection based on these seven components is effective because they all contributed equally to fibre yield increment. Bhor et al. (2020), Nayak and Baisakh (2008), and Islam et al. (2001) all found similar results. Fibre yield correlations are used to determine mutual associations rather than relationships. The results showed that the genotypic correlation is stronger for most character pairings than the phenotypic correlation, indicating that environmental influences reduce the relationship between yield and yield contributing characters.

3.4 Direct and indirect effects of morpho-physiological component traits on fibre yield

The results in Figure 1 and Table 4 show the direct and indirect effects of these contributory factors on fibre yield (core diameter, nodes number, days to first flowering, days to 50% flowering, stick weight, plant height, stem base diameter, stem middle diameter, stem top diameter, fresh stem weight with leaves and pod, and fresh stem weight without leaves and pod). Separating direct and indirect effects through other traits is possible by allocating the correlations, allowing for a more accurate interpretation of cause and effect relationships (Wright, 1921).

This research discovered a significant interrelationship between various morpho-physiological and yield components. As a result of interrelationships, these traits define the fibre yield per plant limit and the direct and indirect effects of component characters. The direct and indirect relationships between covariates are investigated using path coefficient analysis (Wright, 1921). Combinations of all direct and indirect effects on first and second-order components on fibre yield, first-order on second-order components and correlation coefficients between components were used to draw a path diagram as in Figure 1. This visual depiction of the pathways leading to fibre yield and the varying influence of each component studied. The core diameter had the most significant direct positive effect (0.723) on fibre yield. Other higher positive direct effects on fibre yield per plant were contributed by fresh stem weight without leaves and pod (0.485), days to 1st flowering (0.167), stick weight (0.148) and nodes number (0.109). As a result, direct selection based on these characters is possible. This finding is consistent with Bhor et al. (2020) and Senapati et al. (2006), who found that *Corchorus* sp. fibre plants served the same purpose. Stem base diameter (-0.332) and stem middle diameter (-0.225) had high and negative direct effects on fibre yield. Still, their significant positive correlations with fibre yield per plant indicated that indirect selection for high-yielding kenaf genotypes could be made because most of the characters had positive indirect effects.

3.5 Two-stage relations

Core diameter, nodes number, days to first flowering, days to 50% flowering, and stick weight are among the morpho-physiological traits that have been grouped as the first-order component. Plant height, stem base diameter, stem middle diameter, stem top diameter, fresh stem weight with leaves and pod, and fresh stem weight without leaves and pod were considered the secondary yield determinants in kenaf. The interdependence of these two components is presented in Table 5.

3.6 The effects of first-order component relationships on second-order-component

Nodes number, days to first flowering, and days to 50% flowering all showed a negative direct effect of first-order components on plant height. In contrast, core diameter and stick weight showed a positive direct effect (Table 5). The largest direct correlation with plant height was found in the stick weight, followed by core diameter. Days to first flowering, days to 50% flowering, and nodes number all showed a positive direct effect on stem base diameter. In contrast, core diameter and stick weight had a negative direct effect. The impact of first-order components on stem middle diameter and stem top diameter revealed that days to first flowering and nodes number had a negative direct effect. In contrast, days to 50% flowering, core diameter, and stick weight positively affected both traits. Only days to first flowering negatively correlated with first-order components on fresh stem weight with leaves and pod, while other parameters had a positive correlation. Days to first flowering, core diameter and stick weight positively affected fresh stem weight without leaves and pod. In contrast, days to 50% flowering and nodes number had a negative direct effect. Furthermore, the largest direct correlation with fresh stem weight without leaves and pod was found in the core diameter, followed by stick weight.

3.7 Yield component of second order

The effects of second-order components on fibre yield per plant are shown in Figure 1. The negative direct effect of fresh stem weight with leaves and pod on fibre yield was low (-0.002) and followed by plant height (-0.068) and stem top diameter (-0.122). However, a highly positive correlation was observed between fresh stem weight with leaves and pod, and fibre yield.

Fresh stem weight without leaves and pod, and stem base diameter were significantly and positively highly correlated with fibre yield per plant and this was mainly a result of the high direct effects of fresh stem weight without leaves and pod (0.549), and stem base diameter (0.511) determines its suitability as a crop improvement selection criterion. This might be attributed to the moderate positive indirect effect on fresh stem weight without leaves and pod on fibre yield through stem base diameter (0.457). Also, fresh stem weight without leaves and pod, and stem base diameter showed positive indirect effects on fibre yield through all other second-order components.

Although plant height and stem base diameter influence fresh stem weight without leaves and pod, the percentage of fresh stem weight without leaves and pod determines its suitability as a crop improvement selection criterion. Following the stem base diameter (0.511) had a direct positive effect on fibre yield. Plant height, which positively correlates with yield, is an important trait contributing to total fibre yield. Therefore, cultivars with higher plant heights are generally preferred for crop improvement. Plant height (-0.068), stem middle diameter (-0.186), stem top diameter (-0.122) and fresh stem weight with leaves and pod (-0.002) had a negative direct effect. Fresh stem weight without leaves and pod had the strongest genotypic and phenotypic relationship with fibre yield, followed by stem base diameter.

4. Discussion

The 12 different morpho-physiological traits showed a significant difference using the combined quantitative data from the two seasons. Genotypic differences in yield components of *H. cannabinus* and *H. sabdariffa* were reported by Ibrahim and Hussein (2006). Differences in minimum and maximum values of the characters showed the presence of diversity between the genotypes. Significant differences between genotypes indicate a lot of genetic variation between them. The genetic variability in any breeding material indicates a higher likelihood of producing desirable plant traits and could be used in heterosis breeding (Oladosu et al., 2015; Khan et al., 2020). Variability in traits such as plant height, fresh stem weight without leaves and pods, stem base diameter, nodes number, stick weight, and fibre weight was reported in kenaf by Ryu et al. (2017). Ibrahim and Hussein (2006) reported on the variability in the number of capsules per plant and plant height in *H. Sabdariffa* L. The coefficient of variation (CV%) estimates the variation in a population, was high for almost all the characters. The results obtained from the univariate analysis indicate the existence of wide diversity among the studied kenaf genotypes. Faruq et al. (2015) supported this claim and made similar reports on 13 morphological and yield parameters in 25 genotypes belonging to nine *Hibiscus* species. Biswas et al. (2018) reported significant variations in seven yield-related traits in tossa jute. Besides improving individual fibre yields, higher variability within planting materials would also enable the selection of progenies suitable for higher density planting further to increase yield potentials on a given land space.

The findings showed that the genotypic correlation is greater than the phenotypic correlation for most character pairs, implying that environmental factors reduce the relationship between yield and yield contributing characters. Al-Mamun et al. (2010) and Mostofa et al. (2002) came up with similar findings. Days to flowering and fibre weight had a non-significant relationship at the phenotypic level, but the rest of the characters were significant. Seven of the yield's eleven auxiliary characters, viz. core diameter, nodes number, stick weight, stem base diameter, stem middle diameter, fresh stem weight with leaves and pod, and fresh stem weight without leaves and pod, were all found to be positively associated with fibre weight at the phenotypic, and genotypic levels, as well as among themselves. Shukla and Singh (1967) found a strong positive relationship between pairs of characters in white jute at the phenotypic, genotypic, and environmental levels. The higher the plant's height and thickness, the more fibre it produces.

According to path coefficient analysis, fibre yield was positively and significantly correlated with all the characters studied, except days to first flowering and days to 50% flowering, which were negatively associated with fibre yield. Days to first flowering had negative direct effects on fibre yield, but they had significant positive correlations with fibre yield per plant, indicating that indirect selection for high yielding kenaf genotypes could be made using stick weight, plant height, and stem middle diameter, all of which had positive indirect effects. Similar findings were reported by Pervin and Haque (2012). The residual effect (R) was 0.61, indicating that other factors influenced fibre yield per plant but were not investigated. The direct effects of fresh stem weight without leaves and pod in this study were higher, even than their respective correlation coefficients, indicating that fibre yield was more important. Green weight per plant and plant height, according to Sawarkar et al. (2014), are also important factors in predicting jute fibre yield.

This strong correlation was caused by the high positive direct effect on yield. Several previous studies on kenaf had similar outcomes. On the contrary, plant height (Islam, 2001; Pervin and Haque, 2012), green weight (Bhor et al., 2020), fresh weight with leaves (Islam et al., 2004), and stick weight (Al-Mamun et al., 2010; Sawarkar et al., 2014) have all been reported to have the greatest positive and direct effects. Because they influence on fibre yield, it is possible to conclude that plant height, green weight and stick weight should be prioritized during selection in kenaf improvement programs.

5. Conclusion

The prominent traits, including fiber and stick weight, have strong and favorable correlations with other agronomic characteristics, which will aid in the selection of improved kenaf genotypes. There was a strong and positive phenotypic correlation between fibre weights for all morphological traits except days to 50% flowering. The critical path coefficient analysis and partitioning of correlation revealed that plant height and stem middle diameter had a positive direct effect and a positive relationship with fibre yield, which may increase fibre yield. This assessment could be advantageous in developing reliable selection indices for desirable agronomic traits in kenaf. Breeders should develop early maturing kenaf genotypes focusing on plant height and stem middle diameter in tropical areas. Future research should investigate molecular approaches to clarify the connection between the two methods and validate the findings of this study.

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