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COMPARATIVE STUDY OF COCOA (*THEOBROMA CACAO* L.) GENOTYPES UNDER ASSAM CONDITIONS OF NORTH EAST REGION OF INDIA

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ABSTRACT

Cocoa is an important plantation crop primarily cultivated in the southern regions of India. Although several cocoa varieties have been released for cultivation across different parts of the country, no variety has yet been specifically recommended for the North Eastern region, particularly Assam, where arecanut is a major cash crop. To address this gap, the present study was conducted to evaluate the performance of thirteen cocoa genotypes for growth, pod yield, and yield contributing traits, as a basis for future research initiatives. Data on growth and yield traits were studied for three years (2022-24), and mean values were used for analysis. Among the genotypes, VTLCH 2 exhibited significantly superior growth characteristics, including plant height, stem circumference, and canopy area. Pod yield across genotypes ranged from 31.05 to 64.80. Genotype VTLCH 2 exhibited significantly higher pod yield and dry bean yield. Additionally, genotypes VTLC 1A, VTLCC 1, and VTLC 19 also demonstrated suitability for the region, consistently producing pod and dry bean yields exceeding 2 kg per tree, regardless of the quality traits assessed. These genotypes can be propagated vegetatively and recommended for commercial cocoa cultivation in the region

***Keywords* :** Cocoa, genotypes, pod, yield, dry beans, Assam.

Introduction

Cocoa (*Theobroma cacao* L.) is an important plantation crop primarily cultivated in the southern parts of India as a mixed crop under palms. It is mainly grown for its beans, which serve as a crucial raw material for the chocolate industry. The major cocoa producing states in India are Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh. Currently, cocoa is cultivated over an estimated area of 1,03,376 hectares, yielding approximately 27,000 metric tonnes (DCCD, 2024). However, the chocolate industry's demand stands at 60,000 metric tonnes, indicating a significant gap that needs to be bridged by enhancing cocoa production. Cocoa being a shade loving crop has acclimatized well as mixed crop under coconut, arecanut and oil palm gardens to maximize income per unit area. In Assam, arecanut is a significant plantation crop, occupying around 67,000 hectares with a production of 50,040 tonnes and a productivity rate of 747 kg/ha (DASD, 2021). The soil and climatic conditions in Assam are highly favourable for arecanut cultivation, which is practiced across the entire state including the Upper, Lower, and Middle regions. Farmers in Assam usually practice mono-cropping with arecanut. Given that cocoa is a semi-shade loving crop, it has potential to be introduced as an intercrop in existing arecanut plantations, providing an opportunity for additional income. Moreover, cocoa cultivation can improve soil organic matter through leaf litter. Research conducted by ICAR-Central Plantation Crops Research Institute, Research Centre, Kahikuchi, has demonstrated that cocoa can be successfully cultivated under arecanut plantations with appropriate management practices (Singh *et al.*, 2020; Elain Apshara *et al.*, 2023). Although cocoa shows promising growth in the region, identifying suitable genotypes for Assam's conditions is critically important. Malhotra and Elain Apshara (2017) also emphasized the need to identify location-specific varieties and genotypes for both traditional and non-traditional growing zones. Evaluation of cocoa genotypes for pod and bean traits is a pre requisite for selecting high-yielding varieties. While several clones and hybrids have been developed for cultivation in southern India, there is limited information available on the performance of these clones in the North Eastern region. Therefore, the present study was undertaken to evaluate the performance of different cocoa genotypes under the agro-climatic conditions of Assam in North East India.

Materials and Methods

Experimental site

A field experiment was conducted for three consecutive years (2022 to 2024) at the ICAR-Central Plantation Crops Research Institute, Research Centre, Kahikuchi, Guwahati, Assam. The research site is located at 20°18' N latitude and 91°78' E longitude, at an elevation of 50 meters above mean sea level (MSL), within the Lower Brahmaputra Valley agro-climatic zone of Assam. The region experiences a sub-tropical climate, with an average annual rainfall of approximately 1,500 mm. The mean maximum temperature ranges from 15°C to 32°C, while the mean minimum temperature varies between 8°C and 22°C. The soil at the experimental site is classified as alluvial clay loam, with a pH range of 4.8 to 5.0.

Experimental design and treatments

Thirteen cocoa genotypes namely VTLCH 1, VTLCH 2, VTLCH 3, VTLCH 4, VTLCC 1, VTLC 5, VTLC 11, VTLC 19, VTLC 1, VTLC 30, VTLC 1A, VTLC 66, and VTLC 61 planted in May 2011, were used as experimental material. These cocoa trees were established at a recommended spacing of 2.7 m × 5.4 m and grown under a 20years old arecanut plantation spaced at 2.7 m x 2.7 m. Cocoa was planted in every alternate row of arecanut, positioned at the center of four arecanut palms to optimize light and space utilization. The experiment was laid out in a Randomized Block Design (RBD) with three replications to ensure statistical validity. All recommended horticultural practices were followed to maintain the overall health and vigour of the crop. In addition, specific crop management practices such as annual pruning were carried out during August to September. Pruning involved the removal of dead or diseased branches, criss crossed limbs, and water shoots emerging from both chupon and fan branches, ensuring proper canopy structure and airflow.

Observation taken and laboratory analysis

Observations on growth parameters such as plant height, stem circumference (measured at 30 cm above ground level), and canopy spread were recorded from six trees per replication during the months of September-October. Canopy spread was measured at the widest points in both East-West (E-W) and North-South (N-S) directions. The canopy area was calculated using the formula: πrl**,** where r = (E-W + N-S) / 4 and $l = \sqrt{(r^2 + h^2)}$**,** with h representing the canopy height. Pod yield was recorded for individual trees in each genotype during every harvest, and the data were compiled to obtain the annual pod yield per tree for each of the three years (2022-2024). Pod and bean characteristics, including pod weight, pod size, husk thickness, husk weight, number of beans per pod, and single dry bean weight, were recorded from mature, ripe pods. For each tree, six harvested pods were used to calculate average pod characteristics. Wet beans were collected and fermented in polybags with holes for one week followed by sun-drying for ten days. Regarding the biochemical analysis, total carbohydrate and starch content of the sample was determined using Anthrone method and total sugar by anthrone's reagent described by (Rangana, 1979). Total phenolic content of the bean extract was estimated using Folin-Ciocalteau reagent and tannin content by Folin-Denis Reagent. The DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging method was used for determining the antioxidant content in cocoa beans. Analyses were carried out in triplicates.

Data analysis

Statistical analysis of the mean and critical difference (CD) values was performed using SPSS software version 26. Principal Component Analysis (PCA) and correlation chart computations were conducted using R software version 4.5.1.

Results and Discussion

Vegetative growth characters of cocoa genotypes

Vegetative growth parameters namely plant height, stem circumference, and canopy area along with pod yield of cocoa genotypes are presented in Table 1. Analysis of the data revealed significant differences among the genotypes for all three growth parameters. Plant height ranged from 2.70 m to 3.45 m across the genotypes. The genotype VTLCH 2 exhibited the highest plant height (3.45 m), while the lowest was recorded in VTLCH 3 **(**2.70 m**).** Similarly, VTLCH 2 also showed the greatest stem circumference. However, was found to be statistically on par with other genotypes including VTLCC 1, VTLC 66, VTLC 11, VTLC 5, VTLC 19, and VTLC 1A. Canopy area varied from 12.67 m² to 19.72 m² among the genotypes, with VTLCH 2 again recording the highest canopy spread. This superior vegetative performance of VTLCH 2 may be attributed to a larger canopy, potentially enhancing photosynthetic efficiency and, consequently, overall growth.

Similar evaluations of these cocoa genotypes were conducted at the ICAR-CPCRI, Vittal, Karnataka. In that study, VTLC 10 was identified as the most vigorous genotype in terms of plant height, girth, and canopy area ten years after planting (Elain Apshara, 2017). Variations in vegetative growth among the cocoa genotypes may result from multiple factors, including environmental conditions, soil moisture levels, nutrient availability, crop management practices, and inherent genetic differences. These observations are consistent with earlier findings reported by Elain Apshara *et al*., (2009); Aikpokpodion *et al*., (2011); Thondaiman *et al*., (2013) and Bhalerao *et al*., (2018).

Pod characteristics of cocoa genotypes

The pod characteristics of thirteen cocoa genotypes are presented in Table 2. Among the genotypes, VTLC 1A produced the highest pod weight, which was significantly greater than that of the other genotypes. This was followed by VTLC 66, which was found to be statistically at par with VTLCH 2, VTLCH 4, and VTLC 61. In terms of pod length, VTLC 1A recorded the greatest value, indicating its superiority in size. However, pod circumference was significantly highest in VTLCH 2, measuring 29.44 cm. These findings are consistent with earlier studies by Elain Apshara (2017), which reported the influence of pod size on pod length and breadth. The current study also highlights that all genotypes recorded pod weights exceeding 350 g, meeting a key selection criterion for pod quality (Elain Apshara, 2010). Ridge thickness of the pods ranged from 1.06 cm to 1.36 cm, with VTLC 61 exhibiting the thickest pod ridges (1.36 cm). Variability in pod traits including pod length, girth, weight, husk weight, and pod wall thickness has been previously documented among 21 superior progenies of diverse cross combinations in cocoa (Elain Apshara *et al*., 2008). The results of the present study are also in alignment with earlier findings by Subramanian and Balasimha (1981) and Mallika *et al*. (1996), further confirming the genetic diversity among cocoa genotypes in terms of pod morphology.

Pod and dry bean yield of cocoa genotypes

Significant differences were observed in pod yield among the thirteen cocoa genotypes evaluated. The average annual pod yield per tree ranged from 31.05 to 64.80 pods. Among the genotypes, VTLCH 2 recorded the highest pod yield per tree (64.80), followed by VTLC 19 (57.52), while the lowest pod yield was observed in VTLCH 3 (31.05). A similar evaluation of the same twelve genotypes at ICAR-CPCRI, Vittal, Karnataka, revealed pod yields ranging from 32.7 to 45.8 pods/tree/year after ten years of planting (Elain Apshara, 2017). In that study, VTLC 5 produced the highest yield (45.8 pods/tree/year), while VTLC 19 yielded 38.3 pods/tree/year under the Vittal agro-climatic conditions. Pod yield variability for other cocoa genotypes such as CCRP 1 to CCRP 10 has also been documented by researchers from Kerala Agricultural University (Sujith and Minimol, 2016) and Tamil Nadu Agricultural University (Sumitha *et al*., 2018), indicating that performance can vary considerably across locations and environmental conditions. The number of beans per pod is a critical yield trait in cocoa. In the present study, VTLCC 1 exhibited the highest number of beans per pod, followed by VTLC 11, whereas VTLC 1 recorded the lowest. These results are consistent with earlier findings on genetic variation in bean count per pod (Enriquez and Soria, 1968; Lachenaud and Oliver, 2005). The single dry bean weight varied from 0.72 g to 1.37 g among the genotypes. VTLC 1A recorded the highest average single bean weight (1.37 g), while the lowest was noted in VTLC 1 (0.72 g). The study also showed that most genotypes produced single dry bean weights exceeding 1 g at 14 years of age, except VTLC 1 and VTLC 61. A single bean weight of over 1 g is considered an important selection criterion to meet international quality standards (GoI, 1997) and to maximize yield, as pod weight, bean size, and single bean weight are the primary contributors to cocoa productivity (Toxopeus and Jacob, 1970; Yapp and Phua, 1987). Regarding dry bean yield, which is influenced by the number of pods, number of beans per pod, and individual bean weight, VTLCH 2 recorded the highest yield. This was statistically on par with VTLC 1A. Four genotypes -VTLCH 2, VTLC 1A, VTLCC 1, and VTLC 19 produced dry bean yields exceeding 2 kg per tree per year, indicating their potential suitability for cultivation under arecanut based intercropping systems in Assam. Variability in dry bean yield among cocoa genotypes has been widely reported and attributed to both genetic and environmental factors (Adomako and Adu-Ampomah, 2003; Iwaro *et al*., 2003; Assemat *et al*., 2005; Maharaj *et al*., 2011).

Biochemical analysis of cocoa beans

The biochemical analysis of cocoa beans is presented in Table 4. Among the genotypes, VTLCH 1 exhibited the highest levels of total carbohydrates, total phenolic content, and tannin content. The total carbohydrate content across genotypes ranged from 25.33% to 57.09%. The study found that differences in total sugar content among the genotypes were not statistically significant. However, total starch content showed variation, ranging from 0.07% to 0.18%. Wollgast and Anklam (2000) reported that biochemical traits such as total phenolic content (TPC), carbohydrates (CHO), and tannin levels can vary depending on factors such as variety, geographical origin, ripeness, and post-harvest conditions including fermentation, drying, roasting, processing, and storage. Cocoa is recognized as a rich source of antioxidants, particularly flavanols and proanthocyanidins. The study also revealed that antioxidant content among the genotypes was relatively high, ranging from 73.89% to 84.81%.

Correlation among growth characters and pod yield of cocoa genotypes

From the correlation chart (Figure 1), it is evident that dry bean yield shows a significant positive correlation with plant height, stem circumference, canopy area, pod yield, and single dry bean weight (SDW). This indicates that an increase in any of these traits is likely to result in a corresponding increase in dry bean yield. In contrast, dry bean yield does not exhibit a significant correlation with other variables such as pod weight, pod length, pod circumference, husk thickness and husk weight. Additionally, pod weight is significantly and positively correlated with pod length, husk weight, and the number of beans per pod. (Mallika *et al*., 1996) also highlighted the importance of these traits in improving cocoa yield.

Principal Component Analysis

Principal Component Analysis (PCA) was conducted to reduce the dimensionality of the data set by transforming a large set of variables into a smaller set that still retains most of the original information. In this study, three principal components were selected based on the eigen value criterion (i.e., eigen values greater than one). These three components together account for more than 80% of the total variance, indicating that they capture the majority of variability present in the data set. As shown in the scree plot (Figure 2(B)), the first principal component (PC1) explains 44.13% of the variance, while the second principal component (PC2) explains 28.25%. Combined, PC1 and PC2 account for 72.3% of the variation, providing a strong two dimensional representation of the dataset. A biplot (Figure 2(A)) was constructed using the loadings of PC1 and PC2. In this plot, the length of the arrows represents the strength of each variable's contribution to the principal components, and their direction indicates the correlation with each component. Additionally, a colour gradient from blue to red illustrates the degree of contribution to the total variance, with red indicating a higher contribution. Variables such as PH, CA, DBY, CF, and SDW show strong positive contributions to PC1, suggesting that they are highly correlated and heavily influence with this component.

Conclusion

Genotype VTLCH 2 exhibited higher mean value for plant height, stem circumference, canopy area, pod circumference, number of pods per tree per year and dry bean yield per tree under arecanut garden at the age of 14 years. Further, genotypes VTLC 1A, VTLCC 1 and VTLC 19 were also found to be suitable for the region with respect to pod yield and dry bean yield (>2kg/tree). These clones can be multiplied and planted commercially for cocoa production in North East region.

Table 1 : Vegetative growth characters and yield of cocoa genotypes

Genotypes	Plant height (m)	Stem circumference (cm)	Canopy area (m^2)	Pod yield (No. of pods tree^{-1}year^{-1})	No of beans pod^{-1}	SDW (g)	Dry bean yield (Kg tree^{-1})
VTLCH 1	2.76	31.65	15.98	41.13	31.03	0.93	1.18
VTLCH 2	3.45	34.27	19.72	64.80	36.92	1.22	2.92
VTLCH 3	2.70	31.69	12.67	31.05	37.64	1.00	1.16
VTLCH 4	2.86	30.21	14.63	42.80	37.00	1.05	1.66
VTLCC 1	3.26	32.94	18.82	52.12	40.47	1.08	2.27
VTLC 61	2.87	26.83	14.12	41.43	34.26	0.86	1.22

VTLC 66	3.18	32.80	17.06	44.65	36.90	1.02	1.68
VTLC 11	3.11	34.23	18.90	44.86	40.26	1.01	1.82
VTLC 5	3.08	32.16	18.56	45.58	31.64	1.02	1.47
VTLC 19	3.30	33.73	19.22	57.52	32.91	1.08	2.04
VTLC 30	3.06	30.44	16.32	38.77	38.16	0.98	1.45
VTLC 1A	3.28	33.88	19.48	49.78	38.58	1.37	2.63
VTLC 1	2.83	28.49	13.98	47.06	29.57	0.72	1.01
Mean	3.05	31.79	16.88	46.27	35.79	1.02	1.73
CD (p=0.05)	0.24	2.46	2.38	6.34	1.92	0.07	0.54

Table 2 : Pod characters of cocoa genotypes

Genotypes	**Pod weight (g)**	**Pod length (cm)**	**Pod circumference (cm)**	**Husk thickness (cm)**	**Husk weight (cm)**
VTLCH 1	450.46	18.99	29.00	1.21	351.36
VTLCH 2	481.82	19.46	29.44	1.07	353.80
VTLCH 3	418.54	19.41	27.74	1.16	301.18
VTLCH 4	476.48	20.48	28.12	1.23	351.67
VTLCC 1	459.06	19.63	28.97	1.07	341.91
VTLC 61	496.40	21.00	28.82	1.36	393.86
VTLC 66	501.07	21.09	29.36	1.11	430.78
VTLC 11	468.38	20.23	28.16	1.06	375.61
VTLC 5	355.68	18.40	27.33	1.06	276.78
VTLC 19	437.54	17.85	29.13	1.13	274.07
VTLC 30	443.33	20.33	27.59	1.17	309.18
VTLC 1A	527.28	23.00	28.26	1.17	370.71
VTLC 1	372.87	17.54	26.92	1.07	345.97
Mean	487.48	19.80	28.15	1.14	344.42
CD (p=0.05)	26.15	0.87	1.03	0.14	22.38

Table 3 : Principle component loadings, Eigenvalue, variance percentage and cumulative variance percentage

	PC1	**PC2**	**PC3**
Plant height (PH)	0.406	0.064	-0.139
Circumference (CF)	0.367	0.094	0.322
Canopy area (CA)	0.392	0.115	0.043
Pod yield (PY)	0.322	0.194	-0.444
SDW	0.369	-0.075	0.255
Dry bean yield (DBY)	0.416	-0.005	-0.104
Pod weight (PW)	0.148	-0.49	-0.206
Pod length (PL)	0.097	-0.50	-0.013
Pod circumference (PC)	-0.008	-0.283	0.519
Husk thickness (HT)	-0.21	-0.312	-0.008
Husk weight (HW)	0.047	-0.433	-0.452
No. of beans pod^{-1}(NBP)	0.237	-0.274	0.292
Eigenvalue	*5.30*	*3.39*	*1.03*
Variance (%)	*44.13*	*28.25*	*8.59*
Cumulative variance (%)	*44.13*	*72.38*	*80.98*

Table 4 : Biochemical analysis of cocoa genotypes

Genotypes	Total carbohydrates (%)	Total sugar (%)	Total starch (%)	Total phenolic content (%)	Antioxidant (%)	Tannins (%)
VTLCH 1	57.09	1.17	0.16	2.17	74.44	1.10
VTLCH 2	26.11	1.18	0.17	1.17	83.33	0.72
VTLCH 3	38.39	1.19	0.09	1.53	82.96	0.49
VTLCH 4	40.48	1.17	0.17	1.69	82.59	0.65
VTLCC 1	25.33	1.18	0.13	1.09	83.15	0.94
VTLC 61	44.12	1.16	0.15	1.52	82.59	0.69
VTLC 66	55.48	1.16	0.16	1.98	73.89	0.51
VTLC 11	44.02	1.17	0.14	1.66	79.26	0.57
VTLC 5	28.98	1.17	0.14	1.12	80.20	0.90
VTLC 19	30.29	1.17	0.15	1.20	84.81	1.02
VTLC 30	28.34	1.17	0.07	1.67	84.63	0.90
VTLC 1A	47.57	1.17	0.17	1.43	76.11	0.60
VTLC 1	52.28	1.15	0.18	2.16	80.19	0.67
Mean	39.88	1.17	0.14	1.56	80.62	0.75
CD (p=0.05)	4.85	0.06	0.02	0.17	4.25	0.27

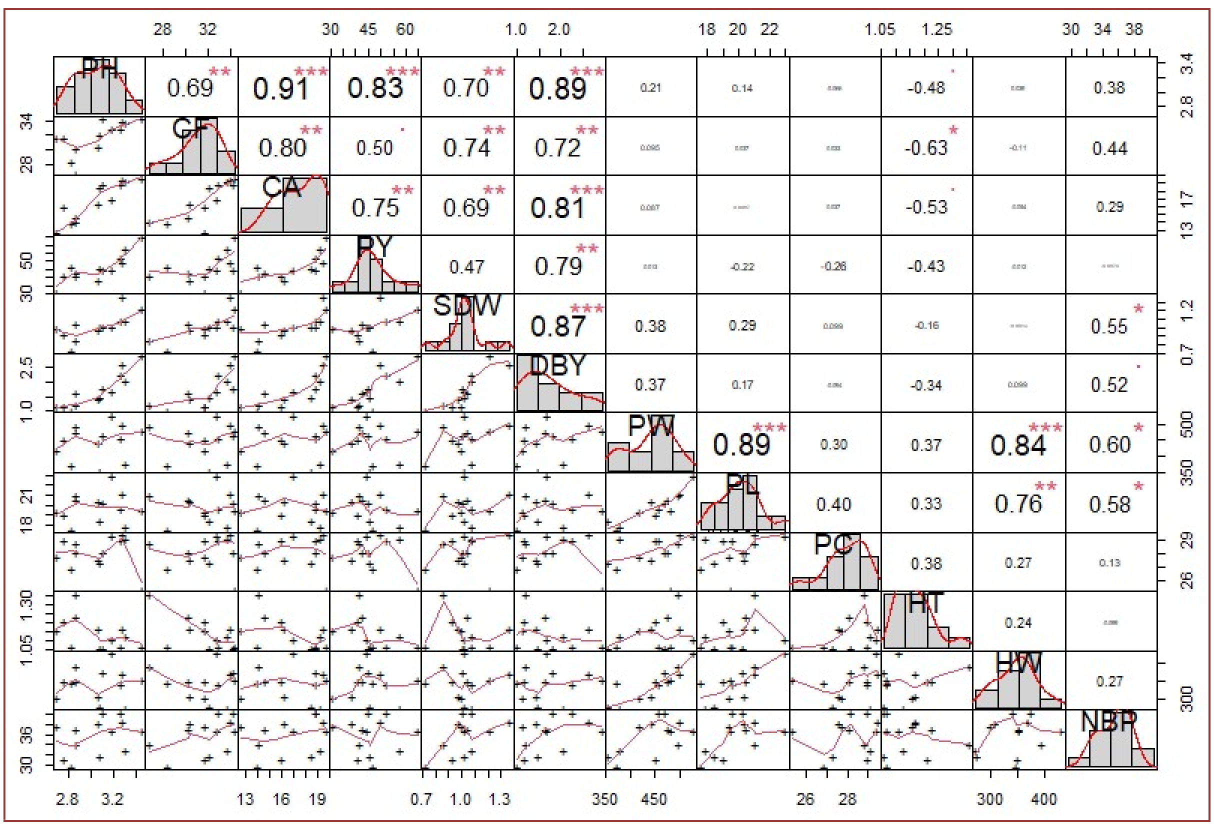

Fig. 1 : Correlation chart for vegetative growth characters, pod characters, and yield of cocoa genotypes

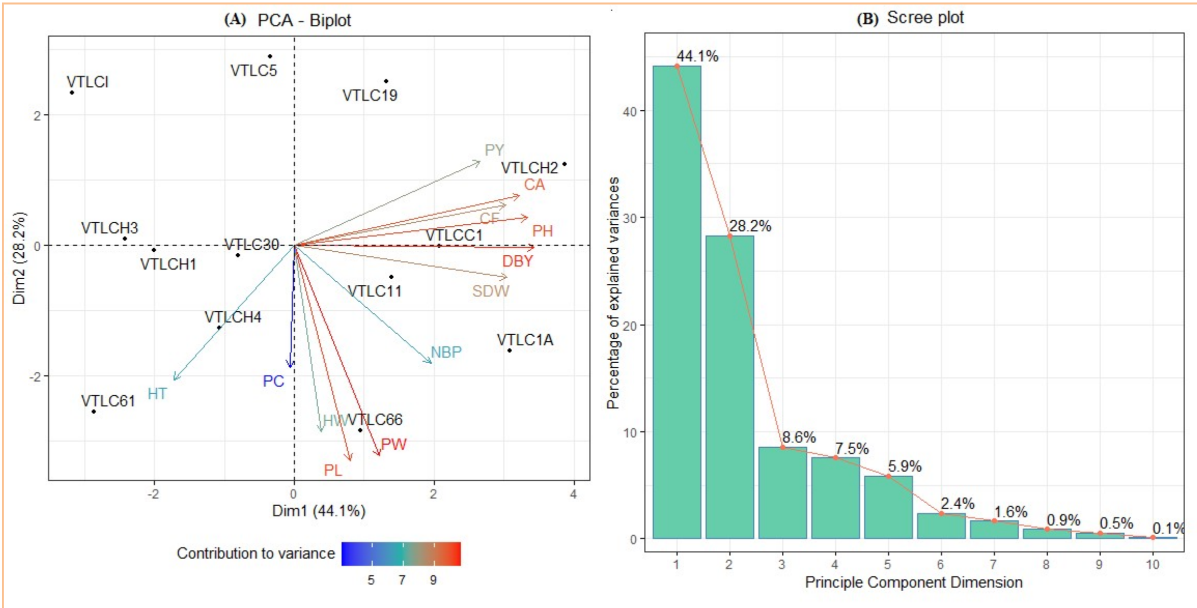

Fig. 2 : (A) Principal component Biplot (B) Scree plot

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