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QUALITY PROFILING OF COCOA (*THEOBROMA CACAO* L.) BEANS UNDER COCONUT-BASED CROPPING SYSTEMS IN COASTAL ANDHRA PRADESH, INDIA

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ABSTRACT

Cocoa (*Theobroma cacao* L.) bean quality is primarily determined by its biochemical composition, which influences flavour, processing and market value. The present study evaluated biochemical traits and developed a region-specific quality profile of cocoa beans cultivated under coconut-based cropping systems in major growing regions of coastal Andhra Pradesh. The study was conducted during 2024–2025 across East Godavari, West Godavari and Srikakulam districts, covering 34 plantations. The mean values recorded were 52.30% fat, 12.12 g/100 g protein, 27.01 g/100 g carbohydrates, 34.20 mg/g phenols and 19.53 °Brix TSS. Fat content exhibited low variability (CV: 6.98–9.25%), indicating stability, whereas phenols showed high variability (CV: 21.04–37.44%). Carbohydrates, protein and TSS displayed moderate variation. Srikakulam recorded higher phenols and TSS, suggesting improved flavour potential, while East Godavari showed greater intra-district variability. The study provides a comprehensive quality profiling framework, which can be utilized for enhancing cocoa production, improving market value and promoting sustainable cocoa cultivation under coconut-based cropping systems in coastal Andhra Pradesh and underscores the importance of site-specific nutrient management and standardized post-harvest practices for consistent quality improvement.

Key words : Cocoa, Biochemical traits, Quality profiling, Coconut-based cropping system, Variability, Coastal Andhra Pradesh.

Introduction

Cocoa (*Theobroma cacao* L.), a member of the family Malvaceae, is one of the most economically significant plantation crops globally, valued for its beans that constitute the fundamental raw material for the chocolate and confectionery industries. The quality of cocoa beans is a key determinant of their market value and industrial suitability, which is largely governed by their biochemical composition. Major constituents such as fat, proteins, carbohydrates, phenolic compounds and total soluble solids (TSS) play a crucial role in defining flavour development, aroma complexity, textural attributes and processing efficiency. In particular, fat content influences cocoa butter yield, proteins contribute to flavour precursors, carbohydrates act as substrates for microbial activity during fermentation and phenolic compounds are associated with bitterness, astringency and antioxidant properties (Afoakwa, 2010).

In India, cocoa cultivation has gained prominence as a remunerative intercrop, especially under coconut-based cropping systems in major cocoa-growing states including Andhra Pradesh, Kerala, Karnataka, and Tamil Nadu. Unlike monoculture systems, intercropping of cocoa under coconut plantations creates a distinct production environment characterized by partial shade, modified microclimate and efficient resource utilization. Coastal regions of Andhra Pradesh have emerged as important hubs of cocoa cultivation due to their favourable agro-climatic conditions, including high humidity, moderate temperatures and suitable soil characteristics.

Despite the increasing importance of cocoa cultivation in coastal Andhra Pradesh, systematic information on the influence of this production system on bean quality remains limited. In this context, quality profiling serves as a comprehensive approach to evaluate multiple biochemical attributes simultaneously, providing deeper insights into trait interactions and regional variability. Therefore, the present investigation aims to assess the biochemical composition and develop a region-specific quality profile of cocoa beans cultivated under coconut-based cropping systems in coastal Andhra Pradesh.

Materials and Methods

Th**e** study was conducted during 2024–2025 across three major cocoa-growing regions of coastal Andhra Pradesh *i.e.*, East Godavari, West Godavari and Srikakulam. The number of plantations selected were 10 in East Godavari, 18 in West Godavari and 6 in Srikakulam. Unequal sample sizes among districts were due to differences in the geographical spread of cocoa plantations in sampling districts. All the plantations selected were intercropped in coconut and were in between the age of 15 to 20 years. The details of the geographical locations were presented in Table 1. From selected plantations, mature pods were harvested randomly in replications and processed under standardized fermentation and drying conditions (Moisture content 7%). Processed beans were subjected to biochemical analysis.

Table 1 : Geographical location details of cocoa plantations selected for study in East Godavari, West Godavari and Srikakulam districts of Andhra Pradesh.

Cocoa Plantation No.	Latitude	Longitude
1	N 16^{0} 66’7971"	E 82^{0}02’6796"
2	N 16^{0}.67’2536"	E 81^{0}91’6586"
3	N 16^{0} 59’9058"	E 81^{0}92’1465"
4	N 16^{0} 69’3257"	E 81^{0}98’1008"
5	N 16^{0} 65’9576"	E 81^{0}86’2560"
6	N 17^{0}32’9482"	E 82^{0}43’7867"
7	N 17^{0}36’1522"	E 82^{0}40’3639"
8	N 16^{0}97’2983"	E 81^{0}82’5233"
9	N 16^{0} 79’0002"	E 81^{0}77’6139"
10	N 16^{0} 84’6436"	E 81^{0}28’2681"
11	N 16^{0} 77’8223"	E 81^{0}06’9730"
12	N 16^{0} 77’2349"	E 81^{0}05’5283"
13	N 16^{0} 77’1105"	E 81^{0}06’4485"
14	N 16^{0} 77’0940"	E 81^{0}06’8608"
15	N 16^{0} 80’3090"	E 81^{0}09’5762"
16	N 17^{0}12’8222"	E 81^{0}27’7864"
17	N 16^{0}92’1196"	E 81^{0}10’5853"
18	N 16^{0}91’3553"	E 81^{0}11’3591"
19	N 17^{0}07’9050"	E 81^{0}23’0924"
20	N 16^{0} 90’9547"	E 81^{0}15’3105"
21	N 16^{0}.90’9609"	E 81^{0}15’3136"
22	N 17^{0} 06’5954"	E 81^{0}30’4327"
23	N 17^{0} 06’3478"	E 81^{0}27’7976"
24	N 17^{0}.05’4335"	E 81^{0}30’6420"
25	N 16^{0}81’6736"	E 81^{0}10’9794"
26	N 16^{0} 84’7932"	E 81^{0}23’9262"
27	N 16^{0}85’2268"	E 81^{0}25’2186"
28	N 16^{0}85’8085"	E 81^{0}24’3048"
29	N 19^{0} 02’3610"	E 84^{0}69’2353"
30	N 19^{0} 02’6874"	E 84^{0}69’5986"
31	N 18^{0}14’6456"	E 83^{0}64’2243"
32	N 18^{0} 11’4259"	E 83^{0}69’9366"
33	N 18^{0} 04’1611"	E 83^{0}57’3464"
34	N 18^{0} 03’9482"	E 83^{0}58’5763"

Biochemical attributes studied

Phenolic content (mg/GAE/g)

The total phenolic content of cocoa bean samples was quantified following the Folin–Ciocalteu method as outlined by Sadasivam and Manickam (2005).

Protein (g/100g)

Protein content in cocoa bean samples was estimated following the method of Lowry *et al.* (1951).

Carbohydrates (g/100 gm)

Total carbohydrate content of the sample was estimated following the method of Hedge and Hofreiter (1962).

Fat (%)

Fat content in dried cocoa beans was determined using the Soxhlet extraction method with petroleum ether, as per AOAC (2000) and expressed as a percentage. The fat content of the sample was calculated using the following formula:

Percentage of fat content = {(W_2-W_1)/Weight of the sample (100-M)} × 100

Where, W_1- weight of the round bottom flas

W_2- Weight of the flask filled with petroleum ether

M-Moisture content of the sample

Total soluble solids (TSS, °Brix)

Total soluble solids (TSS) content was measured using a pocket refractometer with a range of 0–85 ºBrix. Prior to analysis, the instrument was calibrated using distilled water to ensure accuracy. A few drops of the pulp juice were then placed on the prism surface and the reading was recorded directly. The TSS content of the sample was expressed in ºBrix.

Statistical analysis

The data collected from cocoa plantations across three districts of coastal Andhra Pradesh (East Godavari, West Godavari and Srikakulam) were subjected to statistical analysis using IBM SPSS Statistics. Descriptive statistics including mean, standard deviation (SD) and coefficient of variation (CV%) were computed for all biochemical parameters. To assess the variation among districts, one-way analysis of variance (ANOVA) was performed by considering districts as treatment groups. Mean comparisons were carried out using the least significant difference (LSD) test at 5% probability level, following the procedures described by Panse and Sukhatme (1985). Coefficient of variation (CV%) was calculated to evaluate the relative variability of traits, and CV ranges were used to classify stability levels of biochemical parameters.

Results and Discussion

The performance of cocoa biochemical traits varied significantly among the 34 plantations studied (Table 2). The overall mean values across cocoa intercropped in coconut plantations in major growing regions of coastal AP were 27.01 g/100g for carbohydrates, 34.20 mg/g for phenols, 12.12 g/100g for proteins, 52.30% for fat and 19.53 °Brix for total soluble solids (TSS).

Trait-wise observations

Fat content (%)

Fat content, being a key factor influencing cocoa butter yield, plays a crucial role in determining the processing quality and commercial value of cocoa beans. it typically accounts for about 46–57% of the dry weight of the nib (Lannes *et al*., 2013). Fat content of cocoa beans exhibited remarkably low variation across the studied districts, ranging from 51.65% in Srikakulam to 52.61% in West Godavari, with corresponding coefficient of variation values between 6.98% and 9.25% (Table 3). The narrow range of variation and relatively low CV clearly indicate that fat content is a highly stable biochemical trait under the coconut-based cropping systems of coastal Andhra Pradesh. This uniformity is advantageous for industrial processing, Cocoa butter is a key determinant of processing efficiency, texture, and melting characteristics of chocolate and related products. Therefore, the consistency observed in fat content indicates that cocoa beans produced across these regions are suitable for standardized processing and industrial utilization.

The observed stability suggests that fat accumulation in cocoa beans is under genetic control, influence from external factors such as soil variability and management differences. The coconut-based intercropping system also contributed to this stability by providing a favourable microclimate, including moderated temperature, partial shade and improved soil moisture retention. These conditions help maintain consistent physiological activity and carbon allocation, thereby supporting fat synthesis across plantations.

Phenols (mg/g)

Total phenolic content showed considerable variation among districts, with mean values of 34.69 mg/g in East Godavari, 33.14 mg/g in West Godavari and a relatively higher value of 36.57 mg/g in Srikakulam (Table 3). The coefficient of variation ranged widely from 21.04% to 37.44%, indicating substantial heterogeneity both within and across districts. The particularly high variability suggests that phenolic accumulation is highly sensitive to environmental and management factors. Phenols, being secondary metabolites, are strongly influenced by stress conditions such as light intensity, temperature fluctuations, pest incidence, and soil nutrient imbalance. The relatively higher mean in Srikakulam may indicate favourable stress conditions enhancing phenolic synthesis. Phenols are directly associated with bitterness, astringency, and antioxidant activity, which has significant role in implications for cocoa quality and flavour profile (Mazor Jolic *et al*., 2011).

Carbohydrates (g/100 g)

Carbohydrate content exhibited moderate variation among the districts, with values ranging from 26.13 g/100 g in East Godavari to 27.52 g/100 g in West Godavari, while Srikakulam recorded 26.98 g/100 g (Table 3). The coefficient of variation ranged from 10.97% to 20.49%, indicating moderate variability among plantations. Carbohydrates in cocoa beans are influenced by

Table 2 : Mean performance of biochemical traits of cocoa beans across cocoa intercropped in coconut plantations in coastal Andhra Pradesh.

Plantation No.	Phenols (mg/g)	Carbohydrates (g/100 gm)	Protein (g/100 gm)	Fat (%)	TSS (° Brix)
1	25.40	24.40	10.80	54.26	15.70
2	38.40	25.38	12.76	49.03	15.73
3	32.60	24.94	11.89	53.91	18.51
4	59.30	26.95	15.90	45.23	19.14
5	55.80	29.13	17.90	44.39	19.15
6	24.00	24.00	10.50	58.60	17.67
7	23.00	23.80	10.20	58.00	19.11
8	25.00	32.93	9.85	50.48	18.74
9	31.80	24.88	11.77	54.17	17.15
10	31.60	24.87	11.74	53.23	20.25
11	33.00	24.90	11.80	59.20	21.34
12	32.20	33.66	13.46	50.34	18.78
13	33.30	24.99	11.99	49.66	20.86
14	23.00	23.90	10.30	57.80	19.84
15	27.00	24.40	10.90	56.60	19.97
16	40.80	34.26	12.36	49.29	20.02
17	49.30	42.96	11.76	48.25	20.75
18	36.20	25.22	12.43	50.73	20.32
19	22.00	23.70	10.20	55.12	20.53
20	22.00	23.70	10.10	58.92	20.79
21	28.50	37.79	12.76	50.10	19.13
22	36.70	25.25	12.50	49.58	14.12
23	39.10	25.43	12.86	49.12	16.13
24	33.60	25.02	12.04	51.59	18.33
25	26.00	24.20	10.80	57.90	20.14
26	27.00	24.40	10.90	53.90	19.86
27	44.90	25.87	13.74	49.90	19.81
28	41.90	25.64	13.28	48.95	20.17
29	40.20	25.52	13.03	50.29	21.73
30	41.30	36.39	13.35	47.13	26.98
31	28.00	24.50	11.00	54.65	21.96
32	26.00	24.20	10.70	57.12	22.18
33	39.00	25.42	12.85	50.83	19.09
34	44.90	25.87	13.74	49.89	20.19
Mean	**34.20**	**27.01**	**12.12**	**52.30**	**19.53**
Range	**22.00-59.30**	**23.70-42.96**	**9.85-17.90**	**44.39-59.20**	**14.12-26.98**

photosynthetic efficiency, which depends on factors such as canopy structure, light interception and nutrient availability particularly potassium, which plays a key role in carbohydrate translocation. Differences in soil moisture availability and irrigation practices influence carbohydrate metabolism. The presence of higher values in certain plantations indicates post-harvest handling management, cultivation practices and environmental conditions across districts. Carbohydrates play a crucial role in fermentation, influencing flavour precursor development (Beckett, 2011).

Protein (g/100 g)

Protein content showed moderate variation across districts, with values ranging from 11.90 g/100 g in West Godavari to 12.45 g/100 g in Srikakulam, while East Godavari recorded 12.33 g/100 g (Table 3). Despite the narrow range in mean values, the coefficient of variation (9.60% to 21.15%) indicates notable variability among plantations, particularly in East Godavari. This suggests that protein accumulation is influenced by localized factors such as nutrient management practices and soil fertility status. Since protein synthesis is closely linked to nitrogen availability, differences in nitrogen fertilization, organic matter content and microbial activity across plantations may have contributed to the observed variability. Additionally, environmental factors such as microclimate and crop management practices could also play a role. These findings emphasize the importance of site-specific nutrient management, especially nitrogen optimization, to achieve consistent protein content in cocoa beans.

Total Soluble Solids (TSS, °Brix)

Total soluble solids (TSS) content showed noticeable variation among districts, with values increasing from 18.12 °Brix in East Godavari to 19.49 °Brix in West Godavari and reaching the highest level of 22.02 °Brix in Srikakulam. The coefficient of variation ranged from 8.41% to 12.29%, indicating moderate variability (Table 3). TSS is an important indicator of sugar content and overall pulp quality, which directly influences fermentation efficiency and flavor development in cocoa beans (Afoakwa *et al.*, 2013). The higher TSS observed in Srikakulam may be attributed to better carbohydrate accumulation and favorable climatic conditions that enhance sugar synthesis.

Table 3 : Regional summary of biochemical traits of cocoa beans across cocoa intercropped in coconut plantations in coastal Andhra Pradesh.

Trait	East Godavari (n=10)	West Godavari (n=18)	Srikakulam (n=6)	CV Range (%)
Phenols (mg/g)	34.69 ± 12.99	33.14 ± 8.02	36.57 ± 7.69	21.04 – 37.44
Carbohydrates (g/100 g)	26.13 ± 2.87	27.52 ± 5.64	26.98 ± 4.65	10.97 – 20.49
Protein (g/100 g)	12.33 ± 2.61	11.90 ± 1.14	12.45 ± 1.28	9.60 – 21.15
Fat (%)	52.13 ± 4.82	52.61 ± 3.90	51.65 ± 3.60	6.98 – 9.25
TSS (°Brix)	18.12 ± 1.52	19.49 ± 1.79	22.02 ± 2.71	8.41 – 12.29

Factors such as fruit maturity at harvest, soil fertility, and moisture availability can significantly influence TSS levels. Additionally, microclimatic variations, including temperature and humidity, may also contribute to differences in sugar accumulation.

Conclusion

The present study demonstrated that cocoa bean quality under coconut-based cropping systems in coastal Andhra Pradesh exhibits both stability and variability across biochemical traits. Coefficient of variation provided a reliable measure of trait stability, enabling classification of biochemical parameters based on their variability across districts. Fat content remained relatively uniform across districts, indicating consistency in cocoa butter potential. In contrast, phenolic content and carbohydrates showed considerable variation, reflecting the influence of environmental conditions and management practices. Srikakulam district recorded higher TSS and phenolic content, suggesting enhanced potential for flavour development, whereas East Godavari exhibited greater intra-district variability. These findings emphasize the importance of site-specific nutrient management strategies, standardized post-harvest practices to improve cocoa bean quality. Over all, the study provides a comprehensive quality profiling framework, which can be utilized for enhancing cocoa production, improving market value and promoting sustainable cocoa cultivation under coconut-based cropping systems in coastal Andhra Pradesh.

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