

Integrative Profiling of Nutritional and Phytochemical Constituents in *Bombax ceiba* L. Flowers for Fortified Food Development

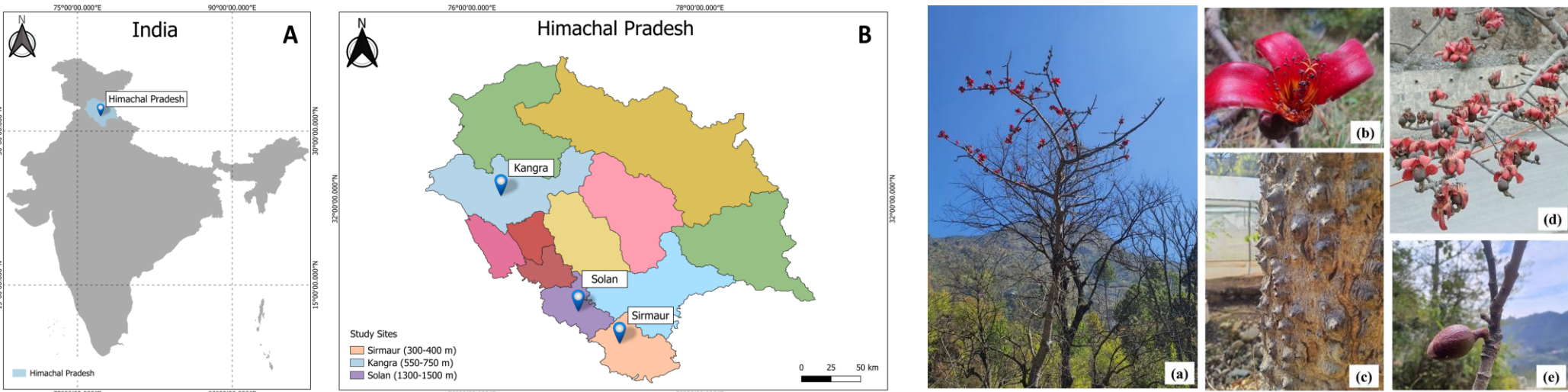
Neeraj Kumari, Sunil Puri

School of Biological and Environmental Sciences, Shoolini University of Biotechnology and Management Sciences, Solan, Himachal Pradesh, 173229, India

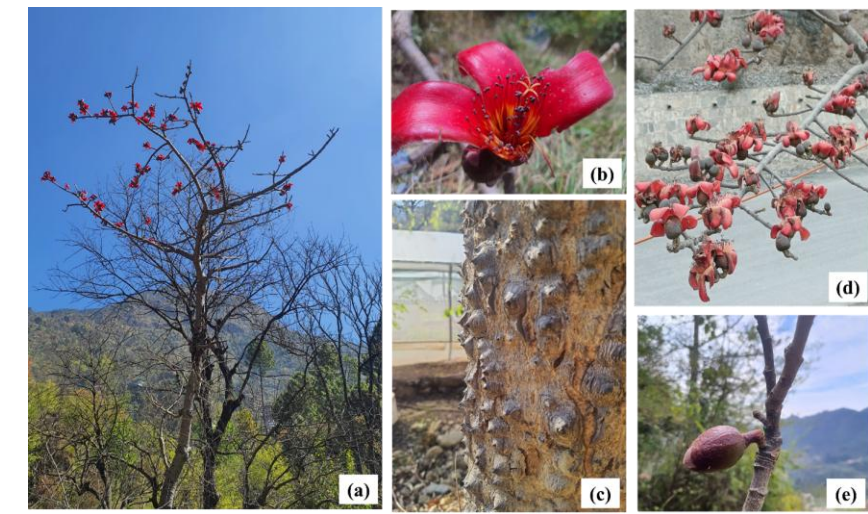
INTRODUCTION & AIM

- In recent years, the demand for nutritious and health-promoting food products has increased, especially after the COVID-19 pandemic (Chaudhari et al., 2024).
- The food industry is now focusing on natural, plant-based ingredients to enhance both functionality and consumer appeal.
- Among traditional medicinal plants, *Bombax ceiba* L. (Malvaceae), commonly known as the red silk cotton tree, has received attention for its rich phytochemical profile and therapeutic potential.
- The large crimson-red flowers are reported to possess hepatoprotective, antioxidant, antimicrobial, and anti-inflammatory properties (Rani et al., 2016; Mir et al., 2017; Jaffar et al., 2023; Kumari et al., 2025).
- The present study aims to evaluate the nutritional and phytochemical composition of different flower components (flower buds, sepals, petals, and whole flower) of *B. ceiba* for its potential as a food product.

MATERIALS AND METHODS

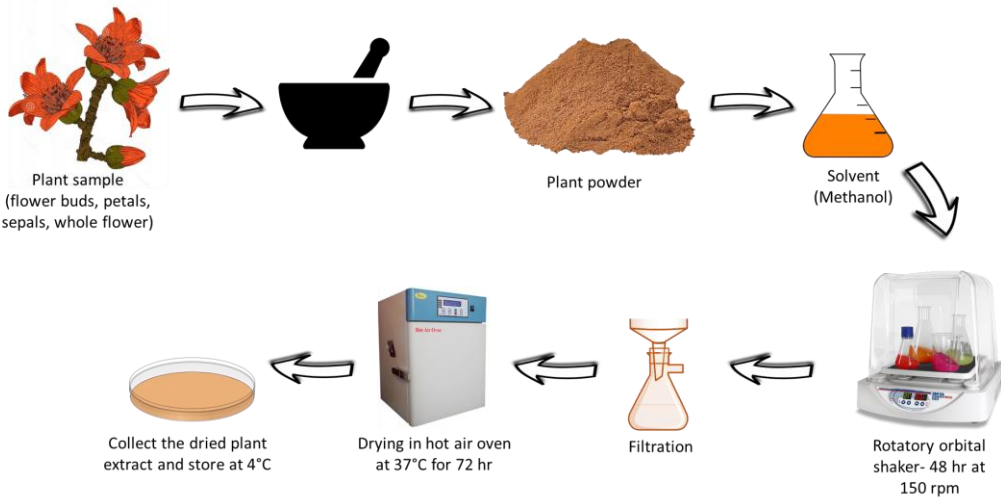


Map of the study sites in Himachal Pradesh, India.



Different parts of *B. ceiba*: (a) Tree; (b) Whole flower; (c) Trunk with thorns; (d) Flowers on branches of the tree; (e) Flower bud.

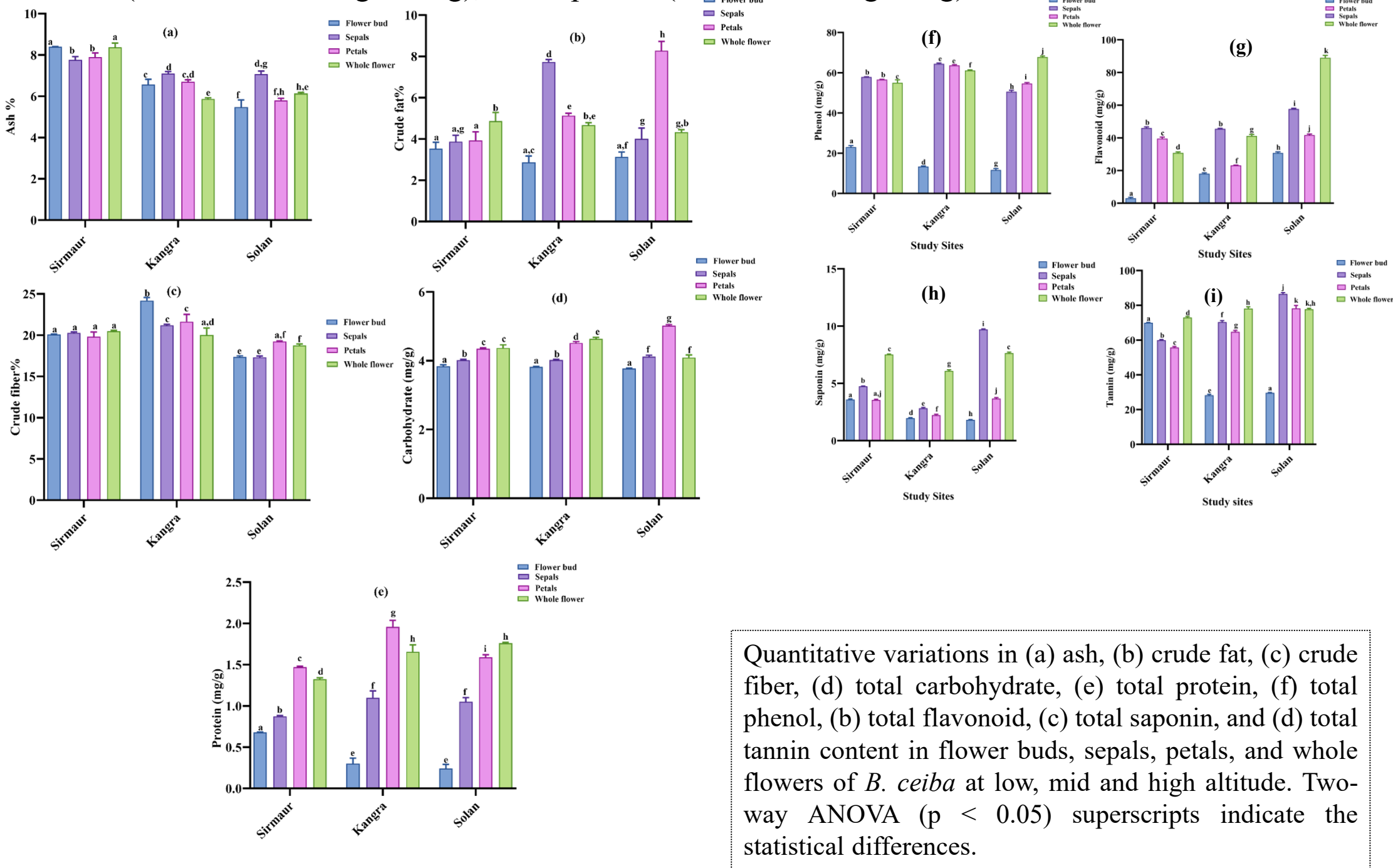
- Nutritional analysis:** Fiber, protein, carbohydrate, fat, and ash using standard AOAC protocols.
- Phytochemicals:** Total phenolics, flavonoids, tannins, and saponins.
- Minerals:** Quantified by ICP-OES.
- Bioactive compounds:** Identified through LC-MS and GC-MS profiling.
- Food product development:** Ready-to-serve (RTS) beverage and jam formulated using blends of *B. ceiba* whole-flower powder with apple pulp in different ratios.



Methodology for the extraction of crude methanolic extract of plant samples.

RESULTS

- Fiber (17.33–24.18%), protein (0.240–1.958 mg BSAE/g), carbohydrates (3.77–5.02 mg GE/g), and fat (3.13–8.27%), ash (5.47–8.40%).
- High levels of total phenolics (11.616–67.774 mg GAE/g), flavonoids (3.022–89.022 mg RE/g), tannins (28.234–86.558 mg TAE/g), and saponins (1.809–9.707 mg DE/g).



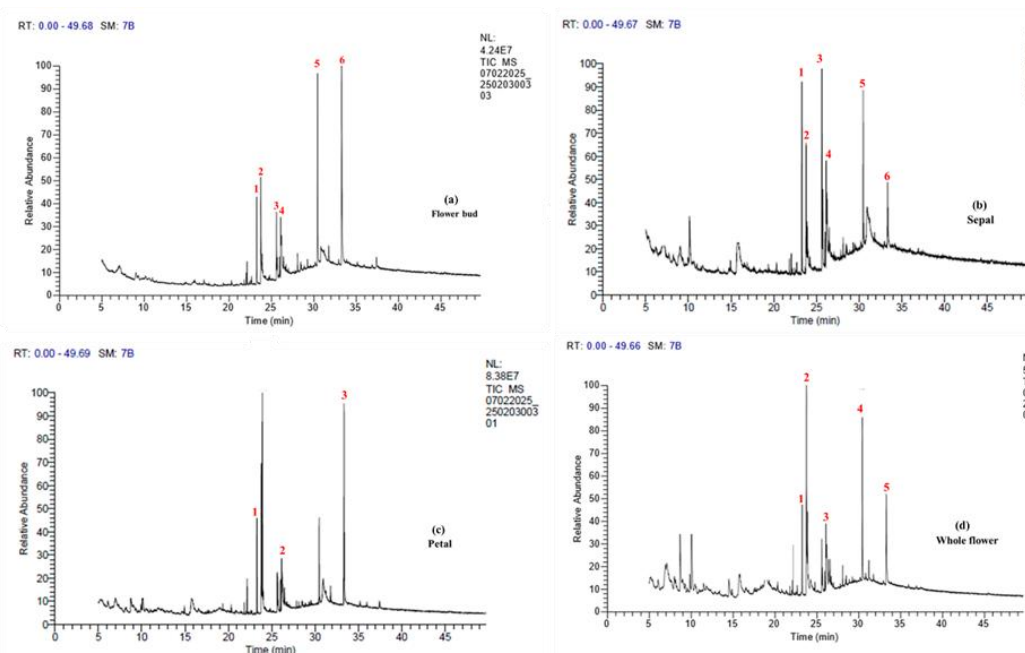
Quantitative variations in (a) ash, (b) crude fat, (c) crude fiber, (d) total carbohydrate, (e) total protein, (f) total phenol, (g) total flavonoid, (h) total saponin, and (i) total tannin content in flower buds, sepals, petals, and whole flowers of *B. ceiba* at low, mid and high altitude. Two-way ANOVA ($p < 0.05$) superscripts indicate the statistical differences.

RESULTS

- All floral parts were rich in minerals: calcium (91.65–314.34 mg/kg), phosphorus (2407.34–5942.51 mg/kg), iron (34.35–337.03 mg/kg), zinc (5.50–17.30 mg/kg), manganese (4.53–37.92 mg/kg), and copper (4.10–8.15 mg/kg).

Site	Flower part	Calcium	Phosphorus	Iron	Zinc	Manganese	Copper
Sirmaur	Flower bud	149.19	3992.89	34.35	7.32	4.53	4.99
	Sepals	139.35	2976.17	38.11	12.85	7.19	5.52
	Petals	253.39	5243.96	210.90	16.99	28.74	7.33
	Whole flower	133.34	2407.34	141.59	5.50	9.41	4.10
Kangra	Flower bud	240.01	5249.81	62.66	17.30	10.43	6.17
	Sepals	314.35	4219.23	85.79	13.67	13.11	5.57
	Petals	91.65	2542.90	151.24	35.76	7.84	8.15
	Whole flower	189.00	3882.50	113.10	15.48	12.29	6.15
Solan	Flower bud	201.26	5942.51	42.98	15.82	7.15	6.77
	Sepals	193.33	3272.47	131.68	13.75	23.47	4.59
	Petals	138.34	3415.76	337.03	16.29	37.92	6.55
	Whole flower	166.56	4574.64	87.19	10.43	6.77	4.49

- Major compounds identified include n-hexadecanoic acid, vitexin, and mangiferin, among others.



Major peaks in GC-MS chromatogram of the methanolic extract of *B. ceiba* (a) Flower bud: (1) Hexadecanoic acid, methyl ester, (2) n-hexadecanoic acid, (3) 8,11-octadecadienoic acid, methyl ester, (4) 7,10,13-hexadecatrienoic acid, methyl ester, (5) pentacosane, (6) tetratetracontane; (b) Sepal: (1) Hexadecanoic acid, methyl ester, (2) n-hexadecanoic acid, (3) 9,12-octadecadienoic acid (Z,Z)-, methyl ester, (4) 6,9,12-octadecatrienoic acid, methyl ester, (5) pentacosane, (6) tetratetracontane; (c) Petal: (1) n-hexadecanoic acid, (2) 9,12-octadecadienoic acid (Z,Z)-, (3) pentacosane; (d) Whole flower: (1) Hexadecanoic acid, methyl ester, (2) n-hexadecanoic acid, (3) ethanol, 2-(9,12-octadecadienyloxy)-, (Z,Z)-, (4) pentacosane, (5) tetratetracontane.

5,7-Dihydroxy coumarin	Kaempferol-3-O-pentoside
5-Hydroxyferulic acid methyl ester	Linolenic acid
5-p-Coumaroylquinic acid	Luteolin
7-O-Methylmangiferin	Malic acid
9,12,13-Trihydroxy-octadecadienoic acid	Mangiferin
Apigenin	Monohydroxymethoxyacetophenone
Artemisinin	Myricetin
Caffeic acid	Naringenin-C-glucoside
Chlorogenic acid	Palmitic acid
Dihydromyricetin	p-Coumaric acid
Dihydroxy octadecenoic acid	Protocatechualdehyde
Epicatechin	Protocatechuic acid
Galllic acid	Quercetin
Hesperetin	Resveratrol
Kaempferol 3-O-glucuronide	Rutin

List of some major compounds identified in methanolic extract of *B. ceiba* flower bud, sepal, petal and whole flower using LCMS analysis

- Whole-flower powder was blended with apple pulp for product formulation. Fortified RTS beverage (apple: flower = 10:90) and jam (apple: flower = 25:75) variants showed significantly higher sensory scores ($p < 0.05$), desirable physicochemical composition, and acceptable microbial load.

Treatment	Apple pulp	<i>B. ceiba</i> pulp
T0	100%	-
T1	85%	15%
T2	70%	30%
T3	55%	45%
T4	40%	60%
T5	25%	75%
T6	10%	90%
T7	-	100%



Different formulations of prepared using varying proportions of apple pulp and *Bombax ceiba* flower powder

Parameter	Fortified jam (25:75)	Fortified RTS beverage (10:90)
pH	4.283±0.006	3.703±0.006
Titrateable acidity (%)	0.384±0.064	0.299±0.037
Total soluble solid (°B)	64.333±0.153	10.000±0.000
Total flavonoid content (µg QE/mL)	5.059±0.000	2.320±0.217
Total phenol content (µg GAE/mL)	5.163±0.517	3.141±0.774
Total plate count (10 ² CFU/mL)	0.333±0.577	0.667±1.155
Total yeast and mold count (10 ² CFU/mL)	0.000±0.000	0.000±0.000

CONCLUSION

- Two-way ANOVA ($p < 0.05$) indicated significant differences in nutrient and phytochemical levels among low-, mid-, and high-altitude samples.
- All floral components of *B. ceiba* contain substantial nutritional and phytochemical constituents and essential minerals, with higher-altitude samples showing the greatest abundance.
- Whole flowers collected from higher altitudes exhibited maximum concentrations of phenolics, flavonoids, and minerals, likely due to temperature, UV radiation, and soil variation.
- The developed fortified RTS beverage and jam demonstrated good sensory acceptance, stable physicochemical properties, and microbial safety within FSSAI limits.
- These findings support the potential application of *B. ceiba* flowers as a functional ingredient in fortified and nutraceutical food formulations.

FUTURE WORK

- Evaluate antioxidant and antimicrobial activities of developed food products.
- Assess stability and shelf life under varied storage conditions.
- Explore consumer acceptance and scale-up potential for commercial production.
- Optimization of analytical techniques used for the development of food products.