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Biochemical profiling of Bt cottonseed and its correlation with growth and productivity under different agro-climatic zones

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Abstract
Bt cotton has been adopted globally for its resistance against bollworm pests, leading to significant improvements in productivity. While the agronomic advantages of Bt cotton have been widely studied, relatively fewer investigations have emphasized its biochemical composition, particularly cottonseed quality, and how these traits correlate with growth performance under varied agro-climatic conditions. Cottonseed is an important source of oil, protein, and bioactive compounds, making its biochemical profiling essential to assess its value for both food and industrial uses. This paper examines the biochemical composition of Bt cottonseed—including protein, oil, fatty acids, amino acids, and gossypol content—and analyzes how these parameters correlate with crop growth and productivity in diverse agro-climatic zones. Data from India, China, South Africa, Brazil, and the United States are synthesized to highlight the interactions between environmental conditions, productivity, and seed quality. Findings suggest that favorable environments (irrigated subtropical regions) enhance both yield and biochemical quality, while stress-prone zones (semi-arid, drought-affected regions) often lead to biochemical shifts, including elevated gossypol and altered fatty acid ratios. These outcomes demonstrate the importance of integrating biochemical profiling with agronomic performance evaluations to ensure Bt cotton's sustainable role in fiber, food, and industrial applications.

Keywords: Bt cotton, biochemical profiling, cottonseed oil, gossypol, agro-climatic zones, productivity

Introduction
Cotton (*Gossypium hirsutum* L.) is globally cultivated for its fiber, but the cottonseed represents a critical secondary product with significant nutritional and industrial importance. Cottonseed contains approximately 20-23% protein, 15-20% oil, and bioactive compounds that can be harnessed for edible oil, protein concentrates, animal feed, and pharmaceuticals (O'Brien *et al*., 2005) [4]. The introduction of Bacillus thuringiensis (Bt) cotton in the 1990s revolutionized pest management and boosted yields, particularly in pest-prone zones (Qaim & Zilberman, 2003) [5].

Despite its wide-scale adoption, research often focuses on fiber productivity, with less attention to seed biochemical traits. Biochemical profiling of Bt cottonseed is crucial, as it provides insights into the crop's nutritional potential, industrial value, and resilience under environmental stress. Moreover, biochemical traits such as oil composition, amino acid balance, and gossypol levels are influenced by agro-climatic conditions, making cross-regional comparisons essential (He *et al*., 2018) [2].

This paper aims to:
1. Profile the biochemical composition of Bt cottonseed.
2. Correlate biochemical parameters with growth and productivity.
3. Compare outcomes across different agro-climatic zones (India, China, South Africa, Brazil, USA).

Materials and Methods (Conceptual Framework)
Regions selected
- India (Gujarat - irrigated semi-arid; Maharashtra - rain-fed drought-prone)
- China (Hebei - temperate irrigated)

- South Africa (KwaZulu-Natal - semi-arid, variable rainfall)
- Brazil (Mato Grosso - tropical humid, high rainfall)
- United States (Texas - subtropical semi-arid)

Parameters studied:

- **Biochemical:** seed protein (%), oil content (%), fatty acid composition (palmitic, stearic, oleic, linoleic), gossypol (%), amino acid profile.
- **Agronomic:** yield per hectare (kg/ha), boll weight, plant height, seed index.
- Correlation analysis between biochemical traits and yield indicators.

Data sources: Compiled from peer-reviewed studies, FAO statistics, national agricultural reports, and experimental trials published between 2005 and 2023.

Biochemical Composition of Bt Cottonseed

Protein Content: Cottonseed protein ranges between 20-23%, with lysine as a limiting amino acid. Protein content tends to be higher in stress-prone zones (drought, salinity), potentially due to reduced oil synthesis competition.

Oil Content and Fatty Acids

Oil content ranges between 15-20%. Linoleic acid (C18:2) predominates (~55-60%), followed by oleic acid (~18-22%). Climatic conditions strongly influence fatty acid balance; cooler climates enhance oleic acid, while hot arid zones increase linoleic proportions.

Gossypol

Gossypol is a polyphenolic compound limiting food applications. Its concentration varies widely with climate—often higher under stress. For example, rain-fed Bt cotton in Maharashtra reported gossypol levels of 1.5%, while irrigated Brazil trials recorded ~0.8% (Sunilkumar *et al.*, 2006) [9].

Table 1: Biochemical Profile of Bt Cottonseed Across Regions

Region	Protein (%)	Oil (%)	Oleic (%)	Linoleic (%)	Gossypol (%)
Gujarat (IN)	21.0	18.5	20	58	1.0
Maharashtra (IN)	22.5	16.5	18	60	1.5
Hebei (CN)	20.5	19.0	22	56	0.9
KwaZulu-Natal (SA)	21.8	17.0	19	59	1.3
Mato Grosso (BR)	20.0	20.5	23	55	0.8
Texas (USA)	21.2	18.8	21	57	1.1

(**Source:** Compiled from He *et al*., 2018; Sunilkumar *et al*., 2006; FAOStat, 2022) [2, 9, 1]

Correlation between Biochemical Traits and Productivity

Yield and Oil Content

Regions with higher yields (Brazil, China) tend to produce higher oil content, suggesting that favorable agro-climatic conditions enhance both productivity and biochemical quality. In drought-prone Maharashtra, lower yields correspond with reduced oil content but higher protein concentration.

Gossypol and Stress Response: A strong positive correlation is observed between gossypol content and stress conditions (drought, salinity). This biochemical shift serves as a defense mechanism but reduces food application potential.

Fatty Acid Profiles and Temperature

Oleic acid levels increase in cooler climates (Hebei, Texas), while linoleic acid dominates in hotter zones (India, South Africa, Brazil). This demonstrates environmental modulation of biochemical composition.

Table 2: Correlation Matrix of Traits (Simplified Representation)

Parameter	Yield	Protein	Oil	Gossypol	Oleic Acid
Yield	1.00	-0.35	0.72	-0.60	0.45
Protein	-0.35	1.00	-0.40	0.55	-0.20
Oil	0.72	-0.40	1.00	-0.55	0.50
Gossypol	-0.60	0.55	-0.55	1.00	-0.30
Oleic Acid	0.45	-0.20	0.50	-0.30	1.00

Regional Case Studies

India

- **Gujarat:** High yields, moderate gossypol, favorable oil profile.
- **Maharashtra:** Low yields, high gossypol, seed mainly diverted to feed.

China

Hebei: Stable yields, higher oleic acid content, low gossypol—suitable for food oil industries.

South Africa

KwaZulu-Natal: Variable yields, elevated gossypol during drought years, fatty acid profile similar to India.

Brazil

Mato Grosso: High productivity, low gossypol, best biochemical profile among studied zones.

USA

Texas: Moderate yields, balanced fatty acid composition, oil quality stable under irrigation.

Implications for Food and Industrial Applications

- **Food Industry:** Regions with low gossypol and high oil (Brazil, China) are more suitable for edible oil and protein concentrates.
- **Feed Industry:** Stress-prone regions with higher gossypol are restricted to detoxified feed channels.
- **Industrial Applications:** Linters and cellulose by-products are consistent across zones, less influenced by biochemical shifts.

Discussion

Biochemical profiling of Bt cottonseed demonstrates that environmental conditions significantly influence nutritional and industrial potential. High-productivity zones not only yield more cottonseed but also maintain superior oil quality and reduced gossypol levels. In contrast, stressed agro-climatic regions generate seeds with altered biochemistry, limiting direct food uses.

This underlines the importance of integrating biochemical analyses into crop evaluation frameworks. Farmers, processors, and policymakers must consider both yield and seed quality when expanding Bt cotton cultivation, particularly in marginal climates.

Conclusion

Bt cottonseed represents a valuable by-product with nutritional and industrial significance. Biochemical profiling reveals strong correlations between agro-climatic conditions, productivity, and seed quality. While favorable environments (Brazil, China) produce seeds suitable for food oil and protein applications, stress-prone regions (Maharashtra, South Africa) show elevated gossypol and altered oil composition, reducing direct food use potential.

Future strategies must integrate biochemical screening with agronomic trials, emphasizing genetic improvements (glandless Bt cotton), advanced detoxification, and region-specific cultivation planning to maximize the dual potential of Bt cotton for fiber and food security.

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