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Comprehensive Morphological Characterization of Cowpea (*Vigna unguiculata* (L.) Walp.) Genotypes for Enhanced Breeding Programs in Jammu and Kashmir

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Abstract

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important legume crop that is recognized for its adaptability to diverse climates and nutritional value. In Jammu and Kashmir, however, its genetic diversity is limited, hindering full yield potential. This study aimed to characterize 72 cowpea genotypes from various regions of Kashmir through Distinctness, Uniformity, and Stability (DUS) characterization. Twenty-four agro-morphological traits were assessed following the guidelines of the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA). Key traits, such as stem color, flowering time, pod length, growth habit, and seed characteristics, were evaluated for distinctness and breeding value. The analysis identified promising genotypes such as C15 (medium seed length and black eye color), CP23-3 (high pod count), C32 (spreading growth and late maturity), TPTC-29 (early flowering, erect growth), C28 (tan eye color, medium seed size), and KDC-39 (high seed count per pod, late flowering). The genotypes exhibited favorable traits, such as early flowering, robust growth, strong pod attachment, and varied maturity, supporting breeding programs aimed at improving cowpea yield and adaptability in climate-stressed regions.

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Introduction

Cowpea (*Vigna unguiculata* (L.) Walp.) is a vital leguminous crop that is extensively cultivated for its adaptability to a wide range of environmental conditions, nutritional value, and role in enhancing soil fertility through nitrogen fixation.[1-3] It is particularly important in regions facing climatic challenges, as it provides a reliable source of food and income

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for smallholder farmers.[4,5] In Jammu and Kashmir, where climate variability increasingly affects agriculture, cowpea has significant potential as a climate-resilient crop.[6-8] However, despite its benefits, cowpea cultivation in this region remains underutilized owing to its narrow genetic base, which limits its productivity and ability to adapt to changing environmental conditions.[9,10]

Expanding the genetic diversity of cowpea through targeted breeding programs is essential to overcome these limitations. A broader genetic base offers the potential to enhance key traits such as drought tolerance, disease resistance, and overall productivity, which are critical for ensuring the crop's resilience to environmental stresses.[7,11-14] Previous studies have demonstrated the effectiveness of genetic improvement in crops such as chickpea, where targeted breeding efforts have led to the development of varieties with enhanced resilience to environmental stresses.[15,16] Such advancements underscore comprehensive morphological characterization's importance in identifying genotypes with desirable traits. Morphological characterization based on Distinctness, Uniformity, and Stability (DUS) testing is a critical step in crop improvement programs because it systematically assesses genetic variation across multiple traits and helps breeders identify superior genotypes suited to local conditions.

Morphological characterization is a vital step in identifying genotypes with desirable traits for breeding programs, as it allows for the selection of parent lines that are best suited to local environmental conditions.[17] In Jammu and Kashmir, the genetic diversity of cowpea has diminished, with a preference for small-seeded black-type varieties, such as Warmuth.[18] This loss of diversity underscores the need for urgent conservation efforts and development of high-yielding, climate-resilient cultivars.

This study focused on the DUS characterization of 72 cowpea genotypes sourced from different regions of Kashmir to support breeding efforts to develop high-yielding, climate-resilient cowpea cultivars. The evaluation of 24 agro-morphological traits, including stem color, flowering time, pod length, and seed characteristics, was conducted following the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) guidelines. By identifying genotypes with promising traits, this study contributes to the broader objective of enhancing cowpea cultivation in Jammu and Kashmir, where the crop's potential for food security remains untapped.

Table 1: Passport Data of Studied Cowpea Genotypes

S.No.	Site of Collection	Code of Germplasm Accessions	No. of Germplasm Accessions from Each Location
1	Local Baramulla	cp23-1, cp23-2, cp23-3, cp23-4, cp23-5, cp23-6, cp23-7, cp23-8, cp23-9, cp23-10, cp23-11, cp23-12, cp23-13, cp23-14	14
2	Local Kupwara	TPTC-29, KBC-9, PL-1, CDP-119, TC-901, cowpea local 1, EC528393, PL-4, EC7224035, EC723909, TC7, TC-15	12
3.	Local Ganderbal	kdc-39, kdc-42, kdc-41, kdc-47, kdc-57, kdc-53, kdc-51, kdc-44, kdc-46, kdc-45, kdc-43, kdc-40, kdc-56, kdc-49	14
4	Local Budgam	skc-11, Cowpea skuast-412, wfc-1, wfc-2, wfc-3, wfc-4, wfc-5, wfc-6, wfc-7, CP22-15, CP22-3, DC-15	12
5	Local Shopain	C13, C14, C15, C16, C18, C19, C20, C21, C23	9
6	Local Kulgam	C24, C25, C26, C27, C28, C29, C31, C32, C33, C34, C36	11
Total			72

Material and Methods

Seventy-two cowpea germplasm accessions, along with five check varieties (Gujrat cowpea 3, Plant Lobia 5, Plant Lobia 7, Shalimar cowpea 1, and Shalimar cowpea 2), were sourced from the Dryland Agricultural Research Station (DARS) SKUAST-K (Table 1). The selection criteria ensured a broad representation of the genetic variation sourced from different regions of Kashmir. Twenty-four morphological traits were studied at DARS-Budgam, SKUAST-K, located at 74.83°E longitude, 34.08°N latitude, and 1587 m above sea level, during the Kharif seasons of 2023 and 2024, following the guidelines of the Protection of Plant Varieties and Farmers' Rights Authority and the International Union for the Protection of New Varieties of Plants, to assess distinctiveness, uniformity, and stability.

For DUS characterization, traits were categorized as either quantitative or qualitative. Quantitative traits such as days to 50% flowering, pods per plant, pod length, days to maturity, seeds per pod, seed length, seed test weight, and peduncle length were assessed in defined ranges or categories, enabling structured comparisons across genotypes. Qualitative traits, including stem color, flower color, leaflet shape, pod shape, and seed eye color, were classified based on observable characteristics. This categorization provides a comprehensive approach to DUS assessment, supporting the identification of distinct visual markers and consistent performance traits essential for cowpea breeding programs.

The experiment was conducted using a randomized complete block design with three replicates. Each plot consisted of a row of 1.5 meters long, with a plant-to-plant spacing of 20 cm and a row-to-row spacing of 45 cm. Standard agronomic practices, such as irrigation and fertilization, were uniformly applied to all plots to reduce environmental variability. Data were collected from five randomly selected competitive plants per plot, except for maturity-related traits, which were recorded on a plot basis. The traits evaluated included stem color, stem pubescence, days to 50% flowering, leaf color, leaf surface, leaflet shape, flower color, plant twinning tendency, pods per plant, pod attachment to the peduncle, pod shape, pod length, pod anthocyanin pigmentation at the tip, immature pod color, days to 50% maturity, seed crowding in a pod, seeds per pod, seed eye color, seed length, seed shape, seed color, seed test weight, peduncle length, and plant growth habits. The frequency distribution of each descriptor across the genotypes was also recorded.

Results and Discussion

The DUS (Distinctness, Uniformity, and Stability) characterization of the 72 cowpea genotypes revealed valuable insights into the diversity of agro-morphological traits essential for breeding programs focused on developing resilient, high-yielding cultivars. The analysis, which assessed 24 traits according to DUS guidelines, provided a structured approach to identify genotypes with distinct, uniform, and stable traits that can be targeted for crop improvement, especially in regions such as Jammu and Kashmir (Table 2, Fig 1).

The DUS characterization framework allowed a structured assessment of these traits, forming the foundation for selecting agronomically viable genotypes that meet the requirements for commercial cultivation and market acceptance. The variation observed in stem color, growth habit, pod structure, and seed characteristics provides a rich source of genetic diversity for developing cowpea cultivars suited to various agro-ecological needs, including those of farmers in Jammu and Kashmir and beyond.

Key Findings

Stem Color and Pubescence

The genotypes exhibited a range of stem colors: green (79.17%), Light Purple (12.5%), and purple (8.33%). This diversity in stem color provides opportunities for selection based on regional consumer preferences. Purple pigmentation may enhance stress tolerance through increased antioxidant activity, similar to findings in *Brassica napus*, where purple-stemmed genotypes demonstrated better performance under drought stress.[19] However, further investigation is needed to confirm any direct correlation between stem pigmentation and drought tolerance in cowpea. Differences in stem color could serve as valuable markers for breeding programs targeting specific markets or environments, although their exact benefits require further exploration.

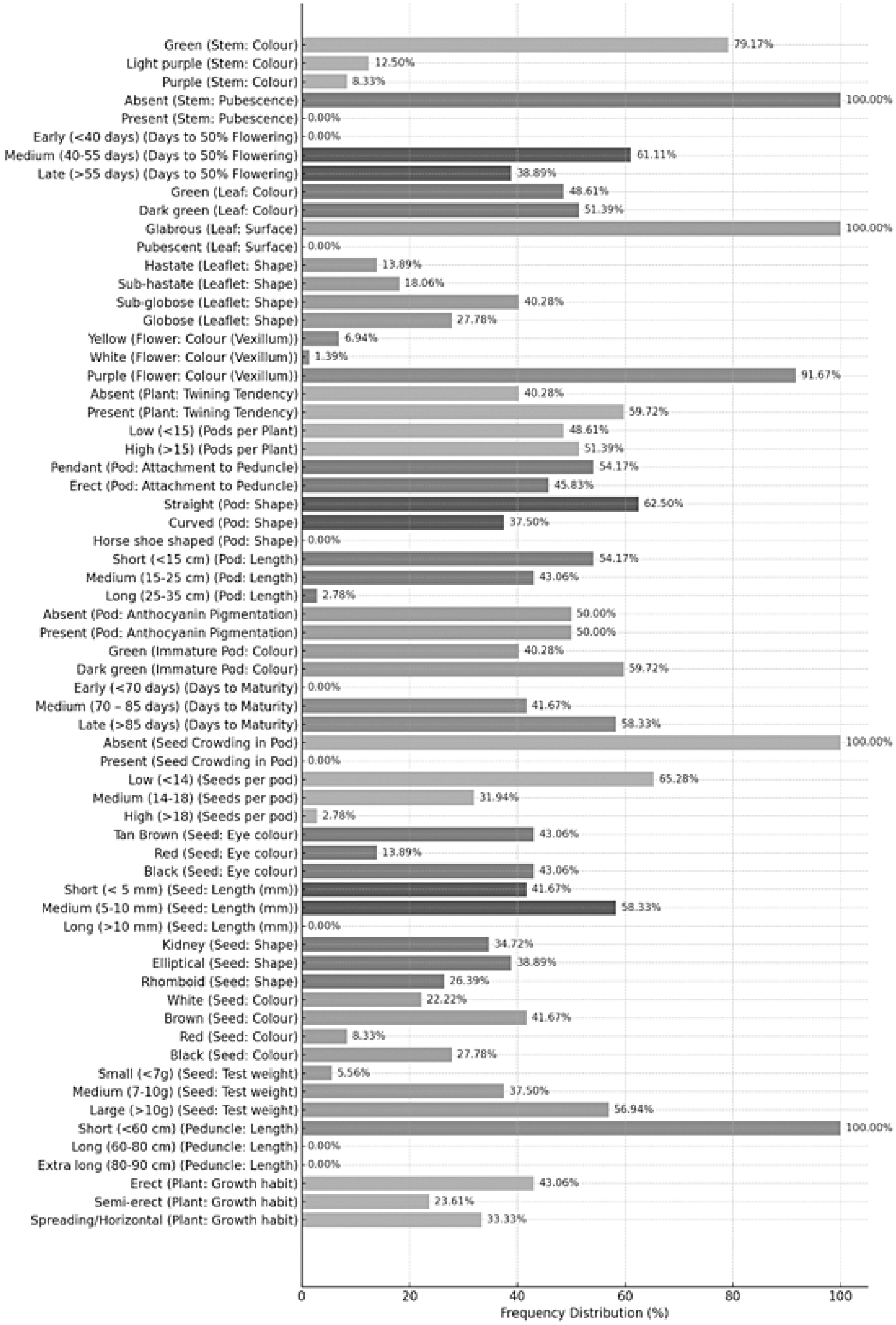

Fig 1: Frequency Distribution of cowpea (*Vigna unguiculata* (L.) Walp.) genotypes for various DUS- characters

Table 2: Frequency Distribution of cowpea (Vigna unguiculata (L.) Walp.) genotypes for various DUS- characters.

S.No	Characteristics	State of Expression	No of Genotypes	Frequency Distribution (%)
1	Stem: Color	Green	57	79.17
		Light Purple	9	12.5
		Purple	6	8.33
2	Stem: Pubescence	Absent	72	100
		Present	0	0
3	Days to 50% Flowering	Early (<40 days)	0	0
		Medium (40-55 days)	44	61.11
		Late (>55 days)	28	38.89
4	Leaf: Colour	Green	35	48.61
		Dark green	37	51.39
5	Leaf: Surface	Glabrous	72	100
		Pubescent	0	0
6	Leaflet: Shape	Hastate	10	13.89
		Sub-hastate	13	18.06
		Sub-globose	29	40.28
		Globose	20	27.78
7	Flower: Color (Vexillum)	Yellow	5	6.94
		White	1	1.39
		Purple	66	91.67
8	Plant: Twining Tendency	Absent	29	40.28
		Present	43	59.72
9	Pods per Plant	Low (<15)	35	48.61
		High (>15)	37	51.39
10	Pod: Attachment to Peduncle	Pendant	39	54.17
		Erect	33	45.83
11	Pod: Shape	Straight	45	62.5
		Curved	27	37.5
		Horse shoe shaped	0	0
12	Pod: Length	Short (<15 cm)	39	54.17
		Medium (15-25 cm)	31	43.06
		Long (25-35 cm)	2	2.78
13	Pod: Anthocyanin Pigmentation	Absent	36	50
		Present	36	50
14	Immature Pod: Color	Green	29	40.28
		Dark green	43	59.72
15	Days to Maturity	Early (<70 days)	0	0
		Medium (70 – 85 days)	30	41.67
		Late (>85 days)	42	58.33
16	Seed Crowding in Pod	Absent	72	100
		Present	0	0
17	Seeds per pod	Low (<14)	47	65.28
		Medium (14-18)	23	31.94
		High (>18)	2	2.78

18	Seed: Eye color	Tan Brown	31	43.06
		Red	10	13.89
		Black	31	43.06
19	Seed: Length (mm)	Short (< 5 mm)	30	41.67
		Medium (5-10 mm)	42	58.33
		Long (>10 mm)	0	0
20	Seed: Shape	Kidney	25	34.72
		Elliptical	28	38.89
		Rhomboid	19	26.39
21	Seed: Color (Main Colour-colour of largest area of seed)	White	16	22.22
		Brown	30	41.67
		Red	6	8.33
		Black	20	27.78
22	Seed: Test weight	Small (<7g)	4	5.56
		Medium (7-10g)	27	37.5
		Large (>10g)	41	56.94
23	Peduncle: Length	Short (<60 cm)	72	100
		Long (60-80 cm)	0	0
		Extra long (80-90 cm)	0	0
24	Plant: Growth habit	Erect	31	43.06
		Semi-erect	17	23.61
		Spreading/Horizontal	24	33.33

The consistent absence of stem pubescence across all genotypes is noteworthy because pubescence is often linked to increased pest resistance. However, while the lack of pubescence could simplify cultivation by reducing the need for specialized pest management, potentially lowering input costs for farmers, and improving the economic feasibility of large-scale cultivation, further studies are necessary to confirm whether this trait has any unintended consequences on pest resistance.[20,21] Additional field experiments focusing on pest pressure could explore this relationship more comprehensively.

Leaf Traits

In terms of leaf traits, the genotypes demonstrated a balance between green (48.61%) and dark green (51.39%) leaves, with shapes ranging from sub-globose (40.28%) to hastate (13.89%). This variation in leaf morphology can be leveraged to optimize light capture and water-use efficiency, which are particularly important in drought-prone environments. The observed variability in leaf shape is consistent with the findings of previous studies, which emphasized the adaptive significance of leaf form in diverse environments, providing breeders with valuable information for improving cowpea adaptability in stress-prone areas.[22,23]

Flower Color

The flower color showed a predominance of purple flowers (91.67%), with a few genotypes displaying yellow (6.94%) or white flowers (1.39%). Purple flowers are thought to enhance pollinator attraction, particularly in regions where bees are the key pollinators. This result aligns with a previous study, which reported that flower color significantly influences natural pollination rates, potentially increasing seed set and overall yields. The presence of other flower colors, although rare, may be beneficial for specific ecological niches or market demands where alternative flower colors are preferred.[24]

Growth Habit

This study revealed a notable distribution of growth habits among the cowpea genotypes, with a significant proportion displaying erect, semi-erect, and spreading habits.

Erect plants (43.06%) were particularly suited for high-density planting systems, where reduced competition for sunlight can enhance growth efficiency. This trait also makes these genotypes ideal for mechanized farming, which is crucial for reducing the high costs associated with manual harvesting in commercial agriculture. A study conducted in the Colombian Caribbean highlighted the need for erect growth habit cultivars because of the high cost of manual harvesting of prostrate genotypes. The study found that erect genotypes showed significant genetic variability and positive correlations between performance components and yield, reinforcing the advantage of selecting erect genotypes for mechanized, high-yielding systems.[25] Similarly, a study using the INTERCOM interplant competition model demonstrated that erect cowpea genotypes are more competitive than semi-erect or prostrate genotypes when grown alongside sunflower, largely because of their leaf area distribution and height growth, which optimize light capture and biomass production.[26] On the other hand, spreading types (33.33%) were more advantageous in low-input agricultural systems, providing better ground cover and natural weed suppression. This diversity provides breeders with options for developing cultivars that can thrive in various agro-ecological settings, thereby optimizing yield and resource efficiency.

Maturity Characteristics

Genotypes displayed variability in flowering and maturity durations, which provides critical flexibility for adaptation to different growing conditions. Medium-flowering genotypes (40-55 days; 61.11%) are valuable for avoiding pest and disease pressure, whereas late-flowering genotypes (>55 days; 38.89%) may withstand early-season droughts. This range in maturity allows farmers to stagger production, offering a strategic advantage in regions with unpredictable growing seasons.[27]

Inflorescence and Pod Characteristics

The observed uniformity in peduncle length (<60 cm) across the cowpea genotypes is a notable structural trait that contributes to the overall consistency of the plant. Studies conducted at ICAR-IIVR have shown that peduncle length, the number of peduncles per plant, and pod length exhibit high genetic variability and heritability levels, indicating their importance in cowpea breeding programs. The positive correlation between pod yield per plant and traits such as the number of peduncles, pod weight, and pod length highlights the role of these characteristics in improving overall yield.[28]

Pod shape and attachment diversity, such as straight (62.5%) versus curved pods (37.5%) and pendants (54.17%) versus erect attachments (45.83%), offer significant opportunities for breeding to meet different market preferences and mechanization needs. It has been highlighted that consumer preferences often favor pod traits that cater to specific harvesting needs, with straight pods being more suitable for mechanized harvesting, whereas pendant pods may be ideal for manual harvesting in smallholder systems.[29] Additionally, seed traits such as shape, color, and eye color are critical factors that influence marketability. It has been observed that consumers prefer larger seeds, which command higher market prices. The variation in seed characteristics, such as elliptical or kidney-shaped seeds, and seed colors, such as black or tan, allows breeders to cater to distinct consumer segments, thus enhancing market adaptability.[30] A team of researchers emphasized the considerable morphological diversity among cowpea accessions in Côte d'Ivoire, especially in seed coat color and shape. Such diversity is essential for varietal selection programs to align consumer preferences and meet regional market demands, thereby enhancing the commercial viability of different cowpea varieties.[31]

Seed Traits

The absence of seed crowding in all genotypes is a promising trait for commercial production because it enhances pod filling and seed quality, both of which are critical for market success. Furthermore, variations in seed shape (e.g., elliptical and kidney-shaped) and eye color (e.g., black and tan) play an essential role in marketability. Studies have demonstrated that consumers purchase cowpea based on specific utility characteristics, such as grain size, testa color, and texture.[30] The hedonic pricing model used in consumer studies suggests that larger seeds are highly valued by consumers, attracting premium prices, and offering higher returns on breeding efforts and R&D. This variation in seed traits helps breeders cater to distinct consumer preferences, thereby enhancing market adaptability and economic profitability.[30]

Furthermore, collecting and characterizing local cowpea ecotypes in Côte d'Ivoire revealed considerable morphological diversity in seed traits such as coat color, shape, and appearance.[31] This diversity, identified through quantitative and qualitative analyses, highlights the potential of varietal selection programs to leverage these traits to improve market adaptability and consumer appeal. The accessions were grouped into 16 morphological groups, demonstrating the genetic diversity available for targeted breeding programs.

The cultural and regional significance of black and tan seed eye colors further influences consumer preferences in different regions. The predominance of medium seed length (58.33%) in most genotypes aligns well with market expectations, offering versatility for both consumption and processing industries. Breeding programs focusing on sorting and grading cowpeas by specific characteristics, such as seed color and texture, can enhance profits by better meeting the targeted market demands.[30]

Implications for Breeding Programs and Future Research

The traits identified through DUS characterization, such as early flowering, robust growth habits, and strong pod attachment, provide promising targets for breeding programs, especially for regions experiencing climate variability. However, future research should focus on assessing untested traits, such as disease resistance and drought tolerance, through field trials to validate the long-term adaptability and resilience of these genotypes.

Promising Genotypes for Breeding

Based on the DUS characterization, several genotypes exhibited traits suitable for enhancing cowpea cultivation across various agro-climatic conditions in Jammu and Kashmir

Genotype C15 from Local Shopain is notable for its black-eye color and medium seed length, aligning well with consumer preferences for black-eyed cowpeas in specific markets. From the Local Baramulla, CP23-3 demonstrates a high pod count and medium flowering time, making it ideal for moderate growing seasons and boosting yield potential.

Genotype C32 from Local Kulgam displays a spreading growth habit with late maturity, which is advantageous for moisture retention and weed suppression in drought-prone areas. TPTC-29 from Local Kupwara exhibits early flowering and an erect growth habit, making it suitable for high-density planting and mechanized farming systems.

With its tan eye color and medium-sized, elliptical seeds, C28 from Local Kulgam meets market demands for larger seeds, enhancing its commercial appeal. From Local Ganderbal, KDC-39 has a high seed count per pod and flowers late, making it suitable for staggered planting and extending the harvest season.

SKC-11 from the Local Budgam, with its high pod count and strong stem structure, can withstand high winds or variable climates, providing stability and support for increased yields. PL-1 from Local Kupwara showed a medium pod count and robust growth habit, making it adaptable to both smallholder and high-input farming systems.

Genotype C31 from Local Kulgam, known for its high pod count and erect pod attachment, is particularly suitable for mechanized harvesting, facilitating efficient yield collection. Lastly, CP23-10 from Local Baramulla, with medium seed length and tan coloration, aligns with regional market demand, especially where tan-colored seeds are preferred.

Conclusion

This DUS characterization of 72 cowpea genotypes provides a structured basis for breeding programs to enhance cowpea cultivation under diverse agro-climatic conditions, particularly in Jammu and Kashmir. The analysis highlighted several genotypes, including C15, CP23-3, C32, TPTC-29, C28, KDC-39, SKC-11, PL-1, C31, and CP23-10, each exhibiting traits beneficial for high yield and regional adaptability. Distinct genetic diversity was observed in traits such as stem color, growth habits, flower color, and pod characteristics, offering valuable options for breeding programs tailored to specific agricultural and market needs. Key traits, such as robust growth habits, high seed quality, and favorable maturity timelines, suggest that these genotypes have strong potential for enhancing resilience and productivity in challenging environments. This foundational characterization guides breeding efforts, with the identified genotypes providing a promising foundation for developing regionally adapted and commercially viable cowpea cultivars. These findings underscore the potential of targeted breeding programs to improve food security and profitability for farmers in Jammu and Kashmir and beyond.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The data supporting this study's findings are available from the corresponding authors upon reasonable request.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Author Contributions

- **Muneeb Ahmad Rather:** Data collection, analysis, and Writing the Original Draft.
- **Ajaz Ahmad Lone:** Conceptualization, Methodology, Supervision.
- **Zahoor Ahmad Dar:** Visualization, Review, and Editing.
- **Saima Fayaz:** Writing, Review, and Editing.
- **Bilal Ahmad Mir:** Visualization, Review, and Editing.
- **Latif Ahmad Peer:** Conceptualization, Methodology, Supervision, Review and Editing.

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