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A comprehensive review of morphological under dus characterization in different maize genotyps (*Zea Mays* L.)

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Abstract
A field investigation was conducted during *kharif 2025*-26 at the Agricultural Research Station, Prof. Rajendra Singh Rajju Bhaiya University Naini Prayagraj to characterize 16 maize genotype based on Distinctness, Uniformity, and Stability (DUS) traits. The experiment was laid out in an Randomize Block Design with three replications, following standard spacing and agronomic practices. Observations were recorded on 31 DUS traits, DUS characters as per the guidelines of PPVFRA (2001) including morphological, leaf, tassel, ear, kernel and root characters. Leaf traits such as Angle between blade and stem, Attitude of blade, Anthocyanin colouration of sheath, Tassel traits such as Time of anthesis, Anthocyanin colouration at base of glume, Anthocyanin colouration of anthers, Angle between main axis and lateral branches, Attitude of lateral branches, Density of spikelets, Ear traits such as length, diameter, shape, Anthocyanin colouration of silks, Number of rows of grains, and position revealed significant diversity. Kernel traits such as Row arrangement, Shape, Kernel: 1000 kernel weight (g.) exhibited long and short ears, which are beneficial for yield. The variation observed among all the DUS traits in the maize genotype provides a valuable resource for hybrid development, varietal registration, and trait-based breeding programs. This diversity supports future research aimed at improving maize for yield, adaptability, and the identification of superior and protectable varieties suited to varied agronomic conditions.

Keywords: Maize, DUS, characterization, morphological traits.

Introduction

According to Anon (2007) [2], around 28% of the maize produced is utilized for food, 11% for cattle feed, 48% for poultry feed, 12% for the wet milling sector (which produces starch and oil), and 1% for seed. This highlights the need for maize in India and the pressing need to create single-cross hybrids with high yields. Consequently, knowledge the breeder might design crossings for better hybrid production with the use of information on the genetic variety of inbred lines. (*Zea mays* L.) Has a high potential for production and a wide range of adaptation. One of the most popular cereals in the world, it Researchers studied the morphological characteristics of plants, and they found that maize (innate in Mexico and Central America. Globally, it is created under a variety of circumstances (Dowswell *et al*., 1996) [12]. It belongs to the Maydeae tribe of the Poaceae grass family and has chromosome number 2n = 20. Three major cereal crops that provide global food security are rice, wheat, and maize (Gull *et al*., 2020) [16]. It is more significant in the worldwide agricultural economy for its industrial value, human food, and animal feed. A basic grasp of genetic variability and variety in a population, as well as the relationships between different traits, is necessary for every successful plant breeding effort (Baishan *et al*., 2010) [4]. Significant genetic variety and a broad range of genetic material are essential for promoting genetic diversity using conventional breeding techniques. Therefore, evaluation and characterization are essential preconditions for both the effective use of germplasm and the identification of new sources for advantageous genes (Gupta *et al*., 2016) [19]. The "Protection of Plant Varieties and Farmers' Rights Act" allows annuals, trees, and vines to be registered and protected for 15 and 18 years, respectively. Only when a variety satisfies the criteria of stability, homogeneity, and individuality can it be registered and protected (Anonymous, 2007) [3]. This suggests that Distinct Uniform-Stable (DUS) features are required of the new variety. This necessitates testing the variety to see if it complies with DUS test requirements (Gupta *et al*., 2015) [18]. According to the PPVFRA (2001) criteria, inbred lines were characterized in order to Differentiate them morphologically using DUS features (Abru *et al*., 2006). With a variety of use, including food, fodder, industrial materials, and bio energy, corn is a significant crop in the globe. The global production of maize (817 million tons) exceeded that of rice (678 million tons) and wheat (682 million tons) in 2009. With little additional land accessible for agricultural production, the globe is currently confronted with the significant task of ensuring food security for an ever-expanding global population. Increasing agricultural output per unit area is one way to address the growing need. In recent years, China has successfully created hybrid maize types with great yields. In 2005, Deng Hai Seeds Company in Laizhou city achieved 19,347 kg ha−1, breaking the global record for summer corn (Yang *et al*., 2009). Duvick (2005) [8] discovered that throughout the last 70 years, breeders had gradually raised the production potential of hybrid maize. Numerous physiological characteristics, such as higher photosynthetic rate (Ding *et al*., 2005, Huang *et al*., 2007) [27, 62], longer leaf area duration (Andrade *et al*., 1993, Andrade *et al*., 1999 [14, 15], Tollenaar and Lee, 2006), larger sink size, high leaf angle (Fellner *et al*., 2003) [38], and shorter anthesis-silking interval (Duvick *etal*., 2004).The new hybrids were more resilient to the pressures brought on by greater plant density as the production potential of hybrid maize grew. This enhanced the potential grain production per unit area by allowing the use of higher plant density to maximize output. The importance of the root system for food production has frequently been disregarded in favor of boosting shoot biomass and grain yield in previous crop and agricultural technology improvements. Because root shape affects a plant's capacity to obtain soil nutrients, the root is an essential plant organ that influences yield (Costa *et al*., 2000) [6].

Characteristics

A total of 16 genotypes of maize that includes in genotypes source from were grown at the Prof. Rajendra Singh Rajju Bhaiya University Naini Prayagraj in the month of July of *Kharif* 2025 with a spacing of 0.6m×0.2m in Randomize block design. During crop growth observations were taken on plant height, leaf angle between blade and stem, type of seed, ear of shape, width of the leaf blade, Leaf: Anthocyanincoloration of sheath, leaf altitude, Stem: Anthocyanin coloration of brace roots, Tassel: Anthocyanin coloration at base of glume, Tassel: Anthocyanin coloration of glumes excluding base, Tassel: Anthocyanin coloration at base of glumes, Tassel: Anthocyanin coloration of anthers, density of spikelet, angle between main axis and lateral branches, density of spikelet, attitude of lateral branches, anthocyanin coloration of silk, color of top of seed, ear placement (cm), ear length, anthocyanin coloration of glumes of ear, kernel row per ear, ear shape, kernel per row, test weight (Madhukeshwar *et al*., 2015) [39].

Morphological features' function in maize under DUS character

Characteristics		**States**	**Stage of observation**	**Type of assessment**
1	**2**	**3**	**6**	**7**
1. (+)	Leaf: Angle between blade and stem (on leaf just above upper ear)	Small (<45 ^{0}) Wide (>45 ^{0})	61	VG
2. (+)	Leaf: Attitude of blade (on leaf just above upper ear)	Straight Drooping	61	VG
3. (S)	Stem: Anthocyanin colouration of brace roots	Absent Present	65-75	VS
4. (+)	Tassel: Anthocyanin	Absent	65	VS
(S)	Colouration at	Present		
	Base of glume			
	(in middle third			
	Of main axis)			
5. (*) (+)	Tassel: Attitude of lateral branches (in lower third of tassel)	Straight Curved	65	VG
6. (*) (+)	Tassel: Angle between main axis and lateral branches (in lower third of tassel)	Narrow (<45°) Wide (>450)	65	VG
7. (*)	Ear: Anthocyanin colouration of silks (on day of emergence)	Absent Present	71	VG
8.	Leaf: Anthocyanin colouration of sheath (below the ear)	Absent Present	71	VS
9.	Tassel: Length of	Short (<20cm)		MS
	Main axis above			
	Lowest side branch	Medium (20-30cm)	75	
		Long (>30cm)		
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10.	Leaf: Width of	Narrow (<8cm)	75	MS
	blade (leaf of			
	Upper ear)	Medium (8-9cm)		
		Broad (>9cm)		
11. (*)	Ear: Length without husk	Short (<10cm) Medium (10-15cm)	92	MS
		Long (>15cm)		
12.	Ear: Diameter	Small (<4cm)	92	MS
	Withouthusk			
	(in middle)	Medium (4-5cm)		
		Large (>5cm)		
13. (+)	Ear: Shape	Conical Conico-cylinderical	92	VG
		Cylindrical		
14.	Ear: Number of rows of grains	Few (£8) Medium (10-12)	92	MS
		Many (³14)		
15. (+)	Kernel: Row arrangement (middle of ear)	Straight Spiral	93	VG
		Irregular		
16. (+)	Kernel: Shape	Shrunken Round	93	VG
		Indented		
		Toothed		
		Pointed		
17.	Kernel:1000	Very small	93	MG
	Kernel weight)	(<100g)		
		Small		
		(100-200 g)		
		Medium		
		(200-300 g)		
		Large		
		(>300g)		

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The type of characteristic assessment listed in Table of Characteristics is as follows:

MG: Measuring a group of plants or plant parts based on a single observation

MS: Quantification of several distinct plants or plant parts

VG: Visual evaluation based on a single observation of a collection of plants

VS: Visual evaluation based on a single observation of a single plant or plant parts

Selection of Traits and Recommendation

- Important qualitative and quantitative characteristics suggested for DUS testing are included in UPOV Test Guidelines TG/2/7 for maize (e.g., leaf, tassel, cob, and kernel features).
- Morphological descriptors are used to assess stability between seed generations, genetic homogeneity within a variety, and distinctiveness from other kinds. They are arranged according to development stage (vegetative, reproductive). (Saha *et al*.)

Importance of Phenotypic Variation

- Breeders may manage and select for genetic differences among inbred lines, hybrids, and landraces by using the morphological variability that DUS descriptors capture.
- Because morphological DUS data are affordable, simple to score, and have a wide range, they are essential for preliminary field characterization prior to molecular studies.

Features of Inbred Lines in Maize

- Morphological DUS descriptors have been used in several investigations to distinguish between inbred lines of maize:
- Wide diversity was detected across 27 morphological DUS features utilized in a research on 16 maize inbred lines, suggesting that these descriptors are useful for characterization.
- Similar research on 70 maize inbreeds supported breeding and variety registration efforts by demonstrating notable variability in attributes such as ear length, tassel characteristics, kernel features, and phenology under DUS testing methods.
- In order to illustrate genetic variety, morphological DUS features were also utilized to create dendrograms that grouped maize lines according to phenotypic distances. (Singh & Marker)

Methods of Phenotyping

- To capture consistent morphological expression, standard DUS techniques advise rigorous field trials with repeated plots and grading at specified developmental phases.
- Each sort of feature has a distinct function in differentiating varieties, ranging from qualitative (like leaf color) to quantitative (like plant height, ear length). (Pandey, H. K., *et al*. 2024) [48].

Morphological DUS's advantages

- Makes it possible to distinguish between closely related cultivars without the need for costly equipment.
- Gives seed regulators and breeders a foundation for formal variety registration and protection under national legislation (such as India's PPV & FR Act).
- Aids in the wide characterization of germplasm, directing the production of hybrids and conservation strategies.

Anthocyanin coloration of leaf sheath,

- A common morphological attribute for describing germplasm (DUS testing) in maize (Zea mays L.) is the anthocyanin coloration of the leaf sheath, which is usually brought on by environmental stressors like cold or low phosphorus (P) availability. This purple or reddish-purple coloration is the result of the buildup of water-soluble pigments, mainly cyanidin and pelargonidin glucosides. (Saritha *et al*.)

Genetic modulate

- Stressors cause some genes (like B1 and Pl1) to modulate pigmentation, which results in the tissue expressing structural genes (like CHS and DFR) differently. (Kumar *et al*.)

Leaf Sheath Specificity

Research has shown that, in nutrient-poor environments, anthocyanin-sensitive maize cultivars (DH605, JNK728, XY335) accumulate more of these pigments in both leaf blades and, more importantly,

Fig 1: Anthocyanin coloration of leaf sheath Absent and Present form Photo taken at the PRSU, Naini, Prayagraj, Research farm.

Leaf: Angle between blade and stem

- One of the most crucial canopy design factors that affect light interception, photosynthetic efficiency, and planting density is leaf angle, which is the slope between the leaf blade midrib and the stem. For many years, modeling techniques have been used to forecast the ideal plant traits that would enhance yield, one of which is leaf inclination.

- The arrangement of the leaves throughout the plant and the process of photosynthesis itself primarily dictate this capability (i.e. the canopy). In order to provide suitable experimental methods for the identification and modification of genes that govern canopy architecture, breeding techniques to increase the carbon fixation capability and yield of economically significant crop species must be updated and reevaluated (Long *et al*., 2006 [34];
- Enhancing the canopy design to prevent individual leaves from becoming saturated with light may increase agricultural output and photosynthetic efficiency. (Zhu *et al*., 2010; Murchie and Nigoyi, 2011) [44].
- According to modeling simulations, plants with an increased leaf angle from top to bottom might enhance carbon absorption by up to 40% compared to canopies with horizontal leaves on a bright day with perpendicular incidence of sunlight. (Long *et al*., 2006) [34]. Recently, Ort *et al*. (2015) [47]
- After the top leaves, which are located above the ear, were manually manipulated to place them at a 10° angle, the hybrid "Pioneer 3306," which was chosen for its high yield and horizontal leaves, demonstrated a 14% increase in grain production in the same research. The light interception capacity of contemporary maize hybrids has increased by 14% when compared to historical materials published between 1930 and the 1960s due to the combination of more erect leaves and a higher LAI. (Lee and Tollenaar, 2007)

Leaf: Angle between blade and stem Wide and Small (<45 ^{0}) form Photo taken at the PRSU, Naini, Prayagraj, Research farm.

Leaf: Attitude of blade

- Photosynthesis, which can greatly increase maize output. According to research, for example, a one-degree increase in leaf angle can result in a 0.1% increase in light interception, which might boost yield. (Lee *et al*., 2008) [29]
- In maize, the leaf angle is genetically regulated. Numerous genes and genomic areas, including those that affect hormone pathways and leaf growth, are linked to the leaf angle. which were the gibberellin and auxin pathways. The Narrow the gene Leaf1 (NEL1) is essential for regulating leaf angle. Leaf blade orientation is influenced by auxin distribution, which is influenced by NEL1. (Dou *et al.*, 2021) [11].
- Leaf angle is greatly influenced by environmental factors such temperature, water availability, and light intensity. Maize plants often modify their leaf angles to optimize light absorption when exposed to low light levels. For example, to boost light interception in shaded areas, leaf angles might rise by as much as 10 degrees. (Tang *et al.*, 2021) [57].
- Future studies should concentrate on comprehending the relationships between leaf angle and several environmental elements, including soil type, water availability, and temperature variations. This information will aid in creating maize cultivars that are more resilient to climate change and can thrive in a variety of environments. The efficiency and precision of leaf angle measurements will increase with the development and use of sophisticated phenotyping methods like artificial intelligence and remote sensing. More accurate breeding and selection decisions may be made thanks to these technologies' ability to deliver real-time data on leaf angle and other agronomic characteristics (Lei *et al.*, 2023) [30].
- Showed more light is intercepted by maize with more horizontal leaf angles, particularly in thick canopies with constrained light availability. For instance, according to (Tang *et al.* 2021) [57], maize plants with a leaf angle of 45° intercepted around 15% more light than those with steeper angles

Tassel: Attitude of lateral branches

The length and circumference of maize ears are important morphological characteristics that affect maize grain production. (Huo *et al.*, 2016) [21] shown that decreased shadowing effects in the maize canopy lead to higher grain production when tassel branches are reduced. Lauer *et al.* (2012) [28] Husk characteristics including breadth, length, and number are crucial for mechanically harvesting maize. (Zhou *et al.*, 2020) [64],

Tassel: Attitude of lateral branches Straight, Curved and Strongly Curved from Photo taken at the PRSU, Naini, Prayagraj, Research farm.

Ear: Anthocyanin colouration of silks

Anthocyanins, which are present in the pericarp, aleurone, and both of these structures, are abundant in maize. [DOI] [PubMed] [Google Scholar]

Vibrant water-soluble pigments called anthocyanins are members of the flavonoid class and give plants' flowers, fruits, leaves, and stems their red, purple, and blue colors. (Alappat and Alappat, 2020; Lin *et al*., 2023).

These pigments have important functions in plant biology that impact genetic and physiological elements in addition to their aesthetic value. (Mannino *et al.*, 2021 [40]).

Anthocyanin-rich maize in agriculture shows greater resistance to pests and environmental stressors, which may lessen the need for chemical pesticides and encourage sustainable agricultural methods. (Câmara *et al.*, 2022).

Ear: Anthocyanin colouration of silks Absent from Photo taken at the PRSU, Naini, Prayagraj, Research farm.

Ear: Length without husk

Female spike primordia (SP) are the first to grow maize ears. According to Vollbrecht and Schmidt (2009) [58], the female SP located in the leaf axil gradually changes into the spikelet-pair meristem, spikelet meristem, and floral meristem of the inflorescence as the shift from vegetative to reproductive growth takes place.

In the end, spikelets produce maize ears of various lengths and thicknesses due to the coordinated influence of several genetic networks controlling inforescence development in maize.

Among the several factors that affect maize production, the length of the ears is crucial in determining how many kernels are planted in a row and has the most beneficial effect on yield (*Jia et al.* 2020; Ning *et al*. 2021) [23, 45].

Consequently, a greater production yield is closely correlated with an increase in maize ear length (EL) (Mendes-Moreira *et al*. 2014; Luo *et al.* 2022) [36, 41].

A multi-parent population was established in this study using five tropical and subtropical maize lines as well as a temperate maize line that showed significant EL differences. These six inbred lines have all been used as parental lines to create elite hybrids and have significant breeding value (Yin *et al.* 2022; Jiang *et al.* 2023; Wang *et al.* 2023) [24, 59, 61].

Ear: Diameter without husk

Higher yield has also been linked to sink characteristics including ear size (both length and diameter), ears per plant, number of ears, kernel size, and number of rows per ear (for a review, see Egli, 2015) [13].

Important morphological characteristics influencing maize grain yield are the length and circumference of the ears (Huo *et al*., 2016) [21].

There are genetic relationships between the husk, ear, and tassel features of tropical germplasm, according to studies on temperate and other maize germplasm (Zhou *et al.*, 2020) [64].

However, both additive and nonadditive effects were seen in tropical maize, influencing ear length, diameter, and circumference (Dhillon and Singh, 1977; Kamara *et al.,* 2020) [9, 25].

Husk characteristics including breadth, length, and number are crucial for mechanically harvesting maize. (Zhou *et al.*, 2020 [64]),

Ear: Length without husk Short, Long and Medium from Photo taken at the PRSU, Naini, Prayagraj, Research farm.

Ear: Diameter without huskSmall, Medium and Largefrom Photo taken at the PRSU, Naini, Prayagraj, Research farm.

Ear: Number of rows of grains

Kernel row number (KRN) is a crucial characteristic for genetically modifying maize to increase yield. As a result, breeding operations for maize have targeted this characteristic. A successful method for raising the overall number of kernels and yield has been the cloning and use of quantitative trait loci (QTLs) for KRN (Hawkins *et al.*, 2013; Lopez-Reynoso and Hallauer, 1998) [20, 35].

The size and continuous differentiation of the inflorescence meristem (IM) are influenced by the genes associated to ear inflorescence development, which encode proteins that regulate the quantity of maize ear kernels (Liu *et al.,* 2021 [11]; Rodriguez-Leal *et al.,* 2019) [51].

A number of tiny chemicals serve as crucial signals that control the growth of maize inflorescences. Auxin, cytokinin, and ethylene are examples of phytohormones, which are naturally occurring small organic compounds that regulate meristem initiation and differentiation. The number of florets and kernels is ultimately determined by these factors (Barazesh and McSteen, 2008; Liu *et al*., 2015; Luo *et al.,* 2022; Ning *et al.*, 2021; Zhang *et al.,* 2018) [5, 32, 36, 45, 63].

The amount of malate in growing inflorescences influences the length of the maize ear via regulating the formation of reactive oxygen species (ROS) and cell proliferation (Pei *et al.*, 2022) [49]. In addition to exposing prospective genetic resources for raising the grain production of maize, these discoveries have clarified the crucial function that small molecules play in the growth of inflorescences.

Ear: Number of rows of grains Few, Medium and Large from Photo taken at the PRSU, Naini, Prayagraj, Research farm.

1000 Kernel weight

Maize yield is strongly impacted by important kernel characteristics such kernel length (KL), kernel width (KW), and 100-kernel weight (HKW). [Google Scholar] [Ref list]

Feature	Description	Variation Stats pmc.ncbi.nlm.nih
Range	9.84-53.78 g	Broad across inbred lines
Distribution	Normal, continuous	Quantitative trait
CV	18% (higher than KL/KW at 8%)	High environmental/genetic influence
Correlations	Positive with KL, KW	Influences overall yield

In our earlier research, we discovered a significant QTL linked to 100 kernel weight (100 KW) in maize that was mapped within the bins 1.03-1.04 on chromosome 1 (qKW1) (Li *et al*., 2011).

The effect of qKW1 on 100-KW was constant across generations and geographical areas. A QTL linked to kernel size and weight has also been found in this genomic area by other research, suggesting that qKW1 is a main-effect QTL with consistent genetic penetrance in wild populations. Guo *et al*., 2008; Yang *et al*., 2012 [60]

Conclusion

The assessment of phenotypic and morphological characterization of many diverse maize (*Zea mays* L.) genotypes in India enhance the important potential for improving maize productivity and production through targeted breeding. The observation of morphological characters under distinctiveness uniformity and stability such as plant height, leaf angle between blade and stem, type of seed, ear of shape, width of the leaf blade, Leaf: Anthocyanincoloration of sheath, leaf altitude, Stem: Anthocyanin coloration of brace roots, Tassel: Anthocyanin coloration at base of glume, Tassel: Anthocyanin coloration of glumes excluding base, Tassel: Anthocyanin coloration at base of glumes, Tassel: Anthocyanin coloration of anthers, density of spikelet, angle between main axis and lateral branches, density of spikelet, attitude of lateral branches, anthocyanin coloration of silk, color of top of seed, ear placement (cm), ear length, anthocyanin coloration of glumes of ear, kernel row per ear, ear shape, kernel per row, test weight seed yield shows the richness of genetic resources available in this agro-climatic zone. This study highlights the superior genotypes with desirable trait combinations as promising candidates for further breeding programs aimed at yield stability and adaptability. Overall, the study provides a vital resource for plant breeders, geneticists, agronomists and helping the development of high-yielding, climate-resilient maize cultivars customized to the specific ecological conditions of the Indian subcontinent, particularly in eastern Uttar Pradesh.

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Author contribution

Contributed to the conception and design of the analysis paper. Contributed to the data collection. Data and analysis tools were used to write the analyzed paper. Also evaluated the paper and then suggested publishing it in this journal.

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