

Characterization of lemma and palea in nine different species of *Eragrostis* (Poaceae)

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Abstract

Eragrostis, the largest genus in tribe Eragrostideae has 36 species in India and with 406 species in the world. The present study investigates the morphological and micromorphological variations of lemma and palea in nine species of the *Eragrostis*, collected from Panchmahal and Dahod districts of Gujarat. Qualitative and quantitative features of microhairs, and epidermal cells in the different regions, apex middle and base of lemma and palea has been observed. Apart from this, undulation patterns also play a key role in species identification. Two major types of undulation pattern \cap and Ω have been observed in the studied species. The present study concludes that, different types of microhairs, size and shape of epidermal cells and its undulating pattern can be significantly used in delimitation of *Eragrostis* with the help of all the qualitative and qualitative characteristic features it was possible to prepare a dichotomous key to identify the nine different species of *Eragrostis*.

Keywords: *Eragrostis*; micromorphology; lemma; palea; undulation

Introduction

Eragrostis Wolf the largest genus having 406 species (POWO, 2021) belong to subfamily Chloridoideae of the tribe Eragrostidae in family Poaceae. These species occur in tropical, subtropical and warm temperate regions throughout the world (Clayton and Renvoize, 1986; Peterson *et al.*, 1993, 2001; Van den Borre and Wasten, 1994). Within in India 36 species (Karthikeyan *et al.*, 1989) and in Gujarat 14 species (Shah, 1978) were recorded. *Eragrostis* the species limits are often overlapping and few agrostologists have attempted to work out on suitable phylogenetic scheme. Based on spikelet disarticulation at maturity, Clayton *et al.* (1974) and Clayton and Renvoize (1986) have arrived at a “first approximation to natural groups” and have presented a key to sections *Psilantha*, *Eragrostis*, *Lappula* and *Platystacha*. Members of *Eragrostis* generally are characterized by panicle inflorescences, multifloreted spikelets, glabrous, three nerved lemmas and ciliate ligules (Zeid *et al.*, 2011).

The best combination of characters used to discriminate this genus from other Eragrostideae is disarticulation of the lemmas and palea occurring separately, longitudinally bowed out paleas with ciliate keels and 3-nerved, unawned lemmas.

Micromorphological characters of different parts of grass are of great value in taxonomic studies of family Poaceae, especially part like leaf (Prant, 1932, 1936; Metcalfe, 1960; Ellis, 1979; Baum *et al.*, 1987;

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Amarasinghe and Waston, 1990). Apart from leaf, characters of floral bracts including lemma and palea are also very important to know the phylogeny and evolutionary relationship between taxa. Micromorphological features useful for the identification and characterization of tribes and subfamilies, for example absence of micro hairs is characteristic in Pooideae (Clayton and Renvoize, 1986). Micro and macro characters have taxonomic significance within genera, as in the case of micro hairs in *Eragrostis* (Amarasinghe and Waston, 1990), being especially useful for the characterization of the larger groups, particularly sub families and tribes. The present study aims to characterize *Eragrostis* at the species level, based on characters of micromorphological characteristic features of lemma and palea.

Materials and Methods

Total nine species of *Eragrostis* were collected from the grasslands of Baria and Godhra forest division of Panchmahal districts. 20-25 individuals of species were gathered and identified Lemma and palea from the lowest floret in the spikelet were carefully separated, washed with distilled water to remove any dust particles adhering to it and used for observations from the apical, middle and basal portions of each part. Observations were carried out first with a stereo microscope and then under light microscope. Terms described by Ellis (1979) was followed for description of micromorphological features. The different spikelets and its parts were photographed with Leica DME microscope.

Results and Discussion

Lemma and palea of Eragrostis

Length of lemma is more than palea in all studied species, except *Eragrostis japonica* and *Eragrostis tenella*. A variation in the number of veins on the surface of glumes have been distinctly noted. In *Eragrostis pilosa* the surface of glumes are smooth with an absence of veins while in all the other species a single the centre of the lemma and palea and in *Eragrostis ciliaris* the number of veins vary form 1 to 3.

Lemma of *Eragrostis tenella* shows glabrous surface while others with scabrous surface. Apex of lemma obtuse in all the species, except *Eragrostis nutans* and *Eragrostis unioloides* with acute apex. Shape of upper and lower glumes ovate except *Eragrostis ciliaris* with lanceolate glumes. All the *Eragrostis* species had an acute apex in both glumes. Lemma and palea of nine species showsn in Figure 1.

Microhairs

Microhairs in grasses are characteristically bicellular. It is commonly found on the leaves but also occur on the other parts like lemma, palea and lodicules (Tateoka *et al.*, 1959; Metcalfe, 1960; Tateoka and Kawano, 1967; Takeota, 1967; Terrel and Wergin, 1981; Scholz, 1985). Their presence and absence are widely used as a taxonomic character (Prat, 1936; Metcalfe, 1960; Waston *et al.*, 1985). Morphologically, microhairs are generally classified into three major types (Tateoka *et al.*, 1959; Metcalfe, 1960; Johenston and Waston, 1979) viz., the 'chlorideae type' with relatively short, broad (approaching hemi spherical) and thick-walled cap cells; the 'panicoid type' with relatively long, narrow and thin walled, elongated cap cells; the 'enneapogon type' with very long basal cells and ovoid cap cells.

Unicellular or bicellular trichomes were prominently seen on glumes. Nerve hairs a common feature noted in *Eragrostis* is characterized by being completely covered by the hairs directed towards the apex. Significant variation has been observed in the density of the hairs. Variations were also found in the apex, basal regions, nerve and marginal hairs.

Characteristic features and terminology used in the present study are as per terminology of the grass inflorescence morphology in Grassbase (Clayton *et al.*, 2006), Ausgrass (Simon and Alfonso, 2011) and Grass

genera of the World (Watson and Dallwitz, 1992). A total of 45 characters were assessed for variability (12 for grass inflorescence and 33 for lemma micromorphology). Characteristic terminology of lemma micromorphology has been followed as per Ellis (1979).

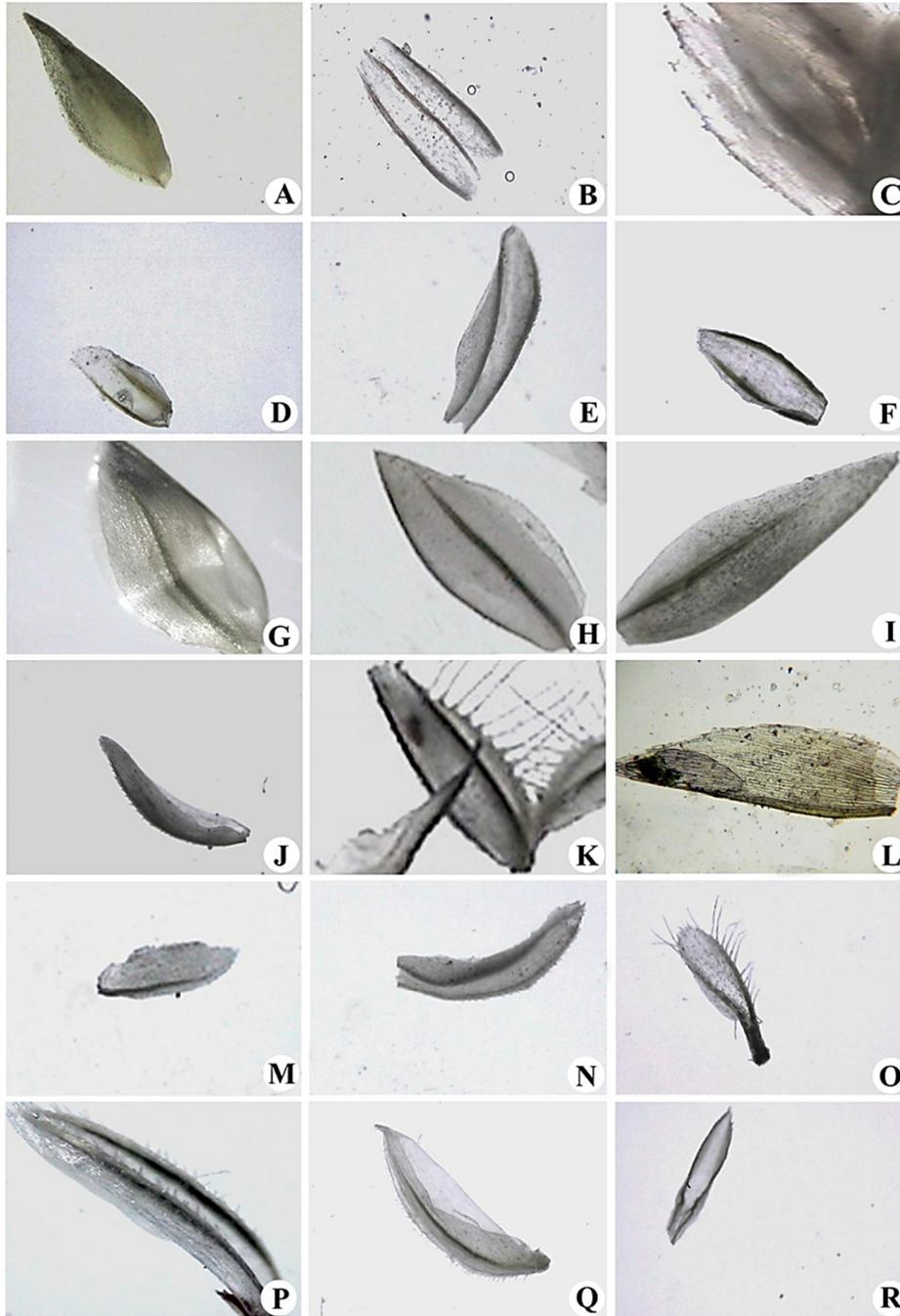


Figure 1. Lemma and palea in nine different species of *Eragrostis*
A-I: Lemma in different species of *Eragrostis*; A: *Eragrostis cilianensis*; B: *Eragrostis ciliaris*; C: *Eragrostis japonica*; D: *Eragrostis nutans*; E: *Eragrostis Pilosa*; F: *Eragrostis tenella*; G: *Eragrostis tremula*; H: *Eragrostis uniolooides*; I: *Eragrostis viscosa*; J-R: Lemma in different species of *Eragrostis*; J: *Eragrostis cilianensis*; K: *Eragrostis ciliaris*; L: *Eragrostis japonica*; M: *Eragrostis nutans*; N: *Eragrostis Pilosa*; O: *Eragrostis tenella*; P: *Eragrostis tremula*; Q: *Eragrostis uniolooides*; R: *Eragrostis viscosa*

Micromorphological description of lemma and palea in Eragrostis

Microhairs

Eragrostis cilianensis

Lemma: Nerves are smooth. At apex region there are 2-3 nerve hairs are present with less density. Multicellular trichomes are present on the surface with less density (Figure 3 A, B, C).

Palea: On nerve spiny, thick walled, rough, unicellular trichomes with broad base. Multicellular trichomes are small compared to one long cell of palea and base is rounded (Figure 2 A).

Eragrostis ciliaris

Lemma: Nerve hairs are not long as of palea. They are unicellular, narrow with broad base, pointed tip, direction towards apex of the lemma, bulbous hairs found at the base region (Figure 2 D). At margin of the lemma there are many unicellular hairs are present which have pointed tip and broad base. Density is more (Figure 2 B, C).

Palea: Broad, long, unicellular hairs rigidly spreading at maturity. Spiny hairs with bulbous base thick walled vary in length arise from the nerve region, long hairs arranged loosely, direction towards the apex with more density (Figure 2 D, E). The short unicellular hairs found on the all over surface, tips are pointed, narrow and long and thin walled. The base is more rounded, density is more at the apex region (Figure 2 F).

Eragrostis japonica

Lemma: Unicellular, small, thin-walled margin hairs and direction towards apex region. Bulbous hairs are found on the surface, density is less. Apex hairs found arranged parallel (Figure 3 E, F, G).

Palea: Spiny, thick walled, rough, unicellular trichomes are present on nerves directing towards the apex of palea. But density is very less, base broad arising from the nerve region. Multicellular bulbous hairs found on the surface with less density (Figure 2 G, H, I).

Eragrostis nutans

Lemma: Unicellular hairs found on the apex region, bulbous hairs (Figure 3 I) are present on the surface, density is less.

Palea: Thick walled, unicellular trichomes are present on nerves of palea. Multicellular bulbous hairs found on the surface with less density (Figure 2 J, K).

Eragrostis pilosa

Lemma: Spiny, thick walled, rough, unicellular nerve hairs are present on nerves directing towards the apex of palea. Base broad arises from the nerve region (Figure 2 L).

Palea: At apex region, 2-3 hairs, thick walled, unicellular, pointed tip, spiny nerve hairs are present, density more, arise from the nerve region, direction towards the apex, having broad base. Bulbous, multicellular hairs are present at the base region. Some globular trichomes with globular tip are also present but density is very less.

Eragrostis tenella

Lemma: Long ciliate, broad, unicellular spiny prickles with bulbous base thick walled vary in length arise from the nerve region. The short unicellular, narrow and long, thin walled, pointed broad tip hairs found on the all over the surface. The base is more rounded and density is more at apex region (Figure 2 M, N).

Palea: Nerve hairs are long, ciliate along the keels, rigidly spreading at maturity, very broad, unicellular, spiny hairs with bulbous base, thick walled and vary in length (Figure 2 O, Q). Density of long hairs is more, arranged loosely and direction towards the apex is not necessary. The short unicellular prickles found on the all over the surface, broad tip which is pointed, narrow, long and thin walled (Figure 2 P). The base is more rounded, density is more found more at the apex region. Multicellular bulbous hairs are also present at the basal region, the cells have rounded cap and long middle region the base is bulbous scattered at the basal region and density is less (Figure 3 M, N).

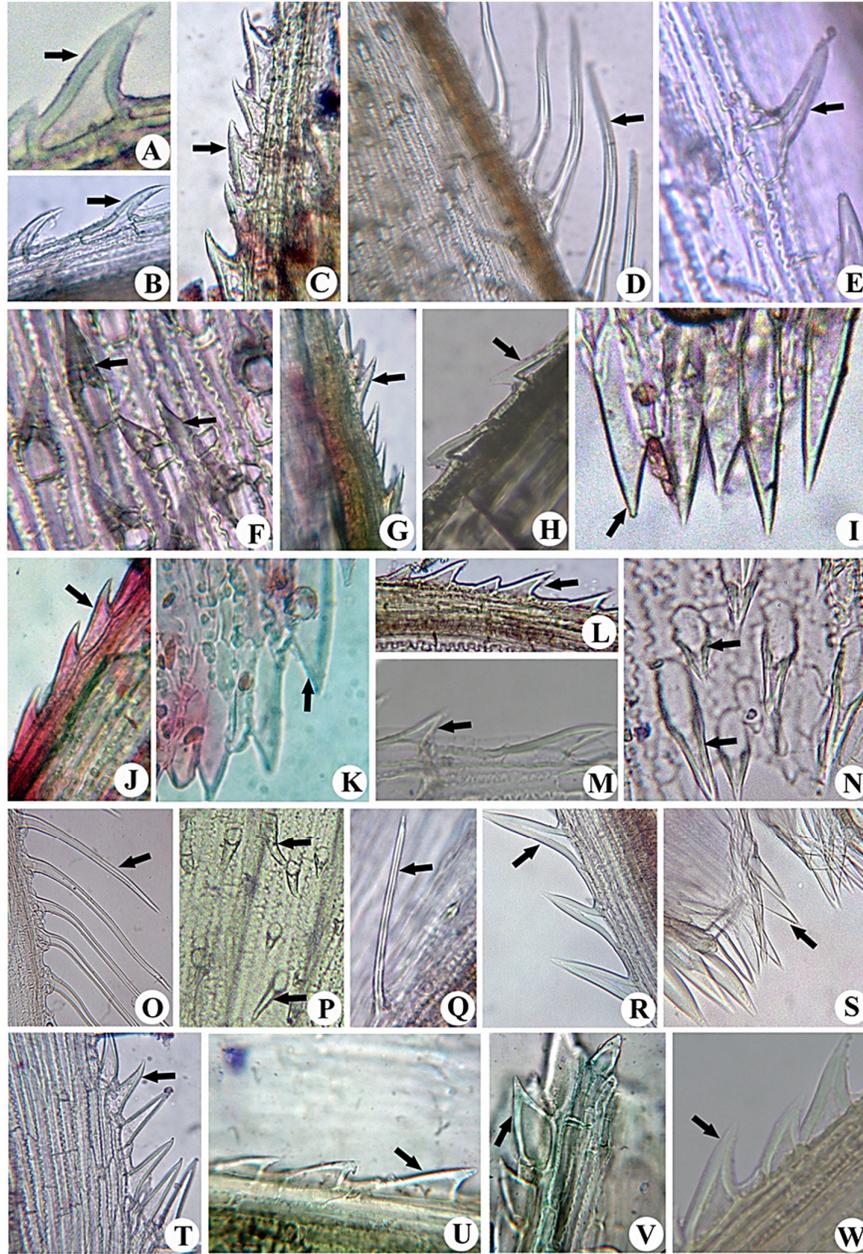


Figure 2. A-W: Hairs macro on lemma and palea of nine different species of *Eragrostis*

A: Unicellular, pointed nerve hairs of *Eragrostis ciliaris*; B: Unicellular, pointed hairs present on middle region of *Eragrostis ciliaris*; C: Unicellular, pointed nerve hairs of *Eragrostis ciliaris*; D: Unicellular, long pointed nerve hairs of *Eragrostis ciliaris*; E: Unicellular, pointed surface hairs of *Eragrostis ciliaris*; F: Prickles of *Eragrostis japonica*; G & H: Unicellular, long pointed nerve hairs of *Eragrostis japonica*; I: Unicellular, long hairs present on apex of *Eragrostis japonica*; J: Unicellular, pointed nerve hairs of *Eragrostis nutans*; K: Unicellular, pointed hairs present on apex of *Eragrostis nutans*; L: Unicellular, pointed nerve hairs of *Eragrostis pilosa*; M: Unicellular, pointed nerve hairs of *Eragrostis tenella*; N: Unicellular, pointed prickles of *Eragrostis tenella*; O: Unicellular, pointed long nerve hairs of *Eragrostis tenella*; P: Unicellular, pointed hairs with bulbous base present on surface of *Eragrostis tenella*; Q: Unicellular, pointed prickles of *Eragrostis tenella*; R: Unicellular, pointed nerve hairs of *Eragrostis tremula*; S: Unicellular, pointed hairs present on apex of *Eragrostis tremula*; T: Unicellular, pointed nerve hairs of *Eragrostis unioloides*; U: Prickles of *Eragrostis unioloides*; V: Unicellular, pointed broad base hairs present on apex of *Eragrostis unioloides*; W: Unicellular, pointed nerve hairs of *Eragrostis viscosa*

Eragrostis tremula

Lemma: Bulbous hairs are found on the surface with less density. At nerve hairs are absent but 1-2 are found at apex region.

Palea: Nerve hairs are long, narrow, base not much broad, unicellular, pointed tip, direction towards apex of the palea, thin walled, smooth surface. Bulbous hairs found at the base region. At the apex region, hairs are found in cluster and are long, narrow with smooth margin and thin wall arise from the tip of the palea (Figure 2 R, S).

Eragrostis uniolooides

Lemma: Unicellular nerve hairs are thin walled, bulbous base direction towards the apex, at the apex hairs are not found. Bulbous hairs are found at the base region.

Palea: Marginal prickles are unicellular, very thin walled, bulbous base, direction towards the apex side (Figure 2 U). Smooth, small, minute, multicellular surface hairs are scattered at the base region (Figure 2 T).

Eragrostis viscosa

Lemma: 1-2 nerve hairs are found at the apex region which are small pointed and thin walled.

Palea: Nerve hairs are thick walled, rough, broad base, pointed tip, unicellular, directing towards the apex. Density is more. They arranged compactly on the margin. Few small multicellular bulbous hairs are present at the base region (Figure 3 T).

Epidermal cells

Micromorphometric features have been represented in Table 1 and 2. Cells present on the surface of lemma are smaller than palea except lemma of *Eragrostis tremula* had more length than the palea.

Eragrostis cilianensis

Lemma:

Apex: Cells are long and narrow. Long cells interrupted by short cells. Undulated wall is loosely arranged. The epidermal long cell walls wavy undulated. The undulations rounded. Most commonly observed straight wall between two cells. Short cell density more (Figure 4 A).

Middle: The cells are long. Undulation is wavy, loosely arranged. The epidermal cells are interrupted by the short cells. The undulation is very loosely arranged and irregular, no particular shape is observed (Figure 4 B).

Base: Cells are long and broad. Short cell density is more. Undulation wavy and loosely arranged (Figure 4 C).

Palea:

Apex: Cells are long and narrow. Undulated wall is compactly arranged. The epidermal long cell walls are \cap -undulated. The undulations rounded, wider towards the apex and slightly narrower at the base. Most commonly observed oblique wall between two cells. Sometimes also seen straight wall too. Various undulation patterns are observed in this region. Short cells are less in number and density is very less (Figure 5 J).

Middle: Cells are long, narrow. Undulations are loosely arranged. Short cells are very less and density is less. The wall between two cells is either oblique or straight. The undulation is wavy, and base is also broad (Figure 4 K).

Base: Cells are long, broad and Interrupted by short cells. The density of short cells is less. The undulation wall is wavy. Undulation is loosely arranged, and the transverse wall is straight (Figure 4 L).

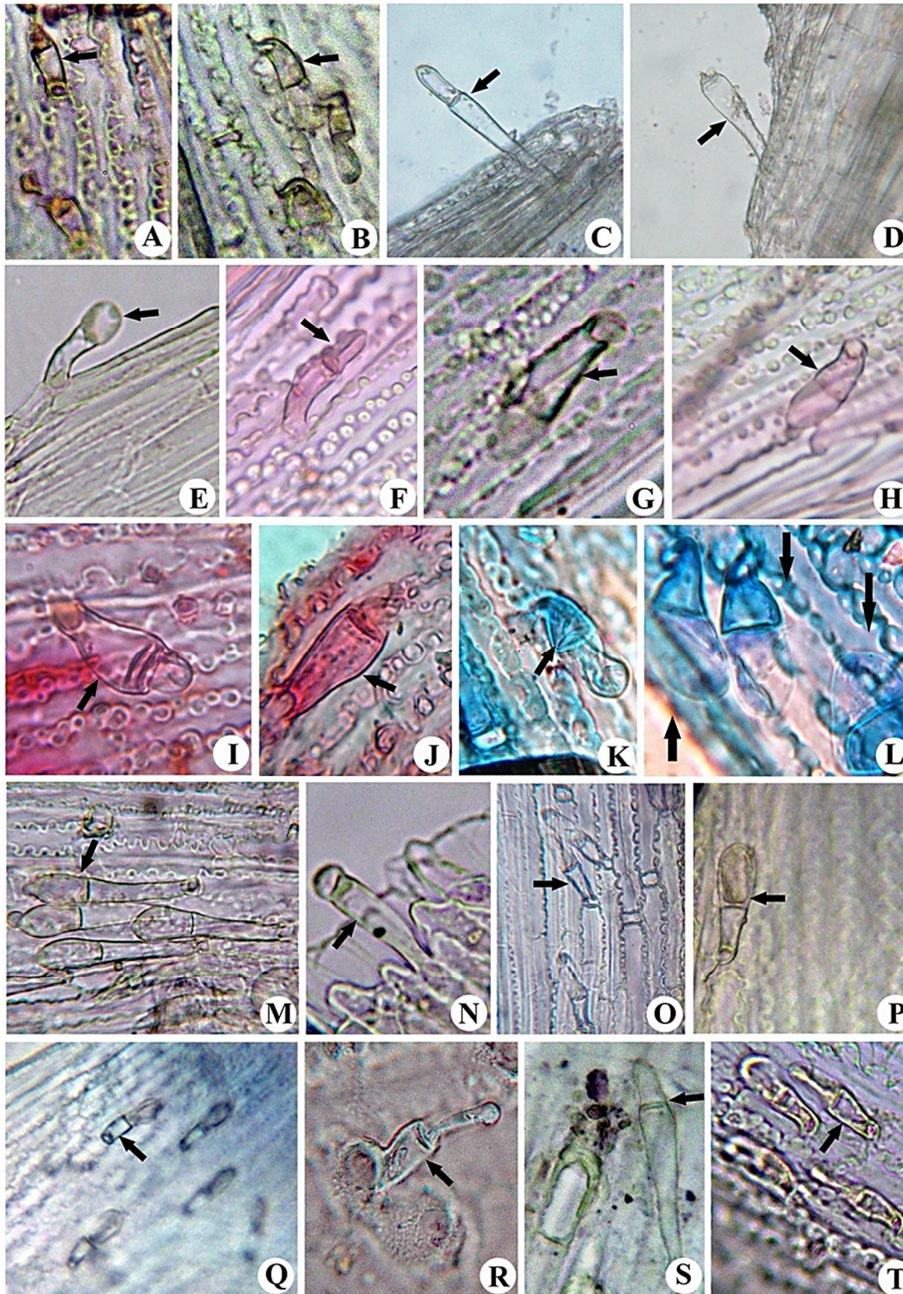


Figure 3. Trichomes of lemma and palea in nine different species of *Eragrostis*
 A: Multicellular, glandular trichome with capitate head of *Eragrostis cilianensis*; B: Multicellular, glandular trichome of *Eragrostis cilianensis*; C: Multicellular trichome of *Eragrostis cilianensis*; D: Multicellular trichome with globular head of *Eragrostis ciliaris*; E, F & G: Multicellular, glandular trichome *Eragrostis japonica*; H: Multicellular, glandular trichome of *Eragrostis nutans*; I: Multicellular trichome with capitate head of *Eragrostis nutans*; J: Multicellular trichome with globular head of *Eragrostis nutans*; K: Multicellular, glandular trichome with capitate head of *Eragrostis Pilosa*; L: Multicellular, glandular trichome with bulbous head of *Eragrostis Pilosa*; M: Multicellular, glandular trichome with capitate head of *Eragrostis tenella*; N: Multicellular, glandular trichome of *Eragrostis tenella*; O: Multicellular trichome with globular head of *Eragrostis tremula*; P & Q: Multicellular, glandular trichome with

capitate head of *Eragrostis unioides*; R: Multicellular trichome with globular head of *Eragrostis unioides*; S: Multicellular trichome of *Eragrostis unioides*; T: Multicellular, glandular trichome of *Eragrostis viscosa*

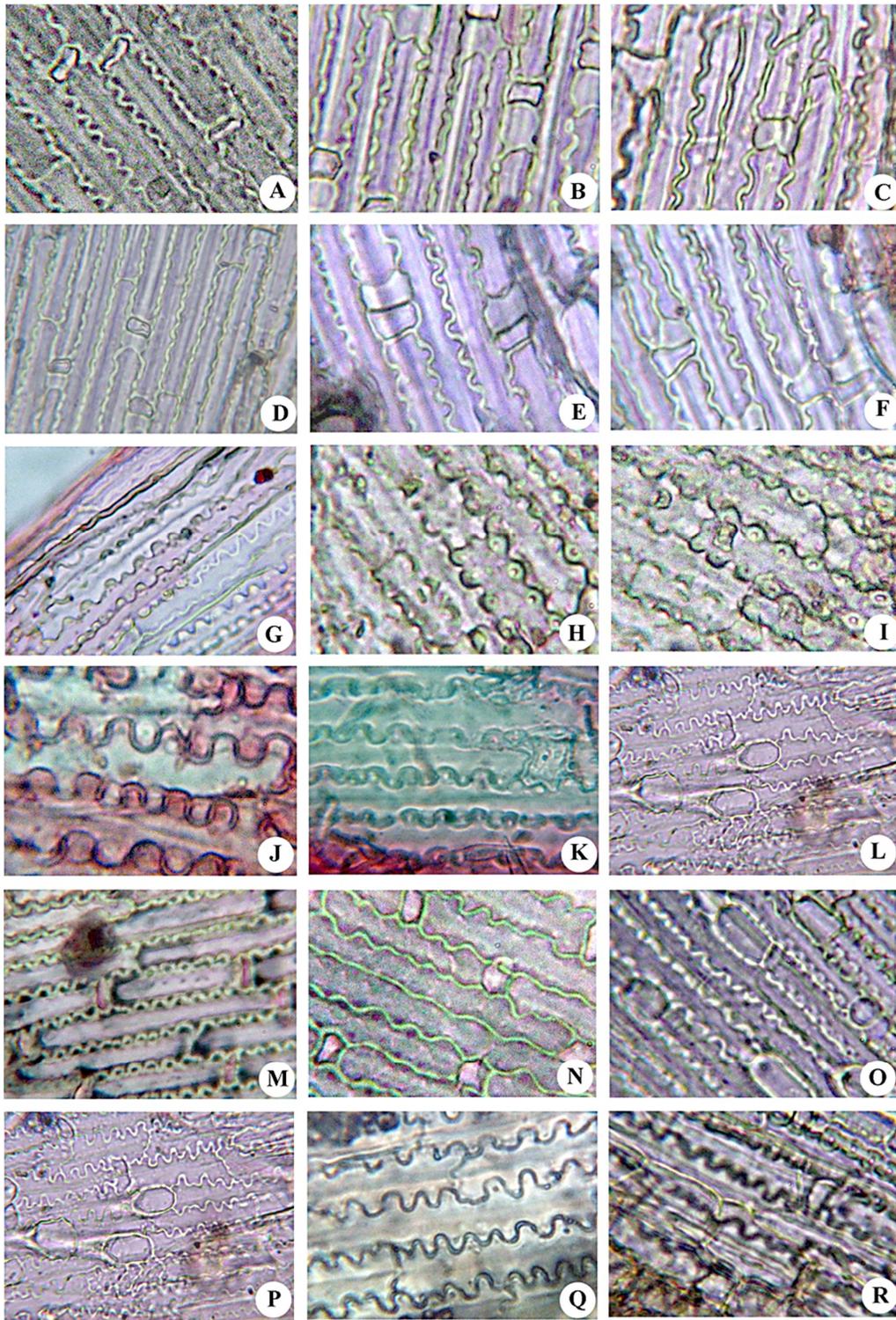


Figure 4. Cells of Lemma in different species of *Eragrostis*

A-I: Variations in cells of Lemma in different species of *Eragrostis*; A-C: *Eragrostis ciliaris*; D-F: *Eragrostisciliaris*; G-I: *Eragrostis japonica*; J-L: *Eragrostis nutans*; M-O: *Eragrostis Pilosa*; P-R: *Eragrostis tenella*; A, D, G, J, M, P: Cells of apex region; B, E, H, K, N, Q: Cells of middle region; C, F, I, L, O, R: Cells of basal region

Eragrostis ciliaris

Lemma:

Apex: The cells are long and interrupted by the short cells with slightly undulating wall (Figure 4 D).

Middle: Cells are very narrow and long. Long cells are interrupted by short cells. The undulation is irregular, wavy, loosely arranged (Figure 4 E).

Base: The cells are long and broad. Undulation is wavy and irregular. Short cells are present more (Figure 4 F).

Palea:

Apex: Cells are not much long and interrupted by short cells. Undulated wall is loosely arranged. The epidermal long cell walls are sinusoidal-undulated. The undulations rounded, narrower towards the apex and wider at the base. Both oblique and straight walls are observed between two cells. Short cells density is more (Figure 5 M).

Middle: Cells are long and wavy. Undulation is irregular, loosely arranged, short cells are very less. The wall between two cells is mostly oblique type and which also shows undulation (Figure 5 N).

Base: The cells are long and narrow. The transverse wall is straight. The undulation is wavy and loosely arranged (Figure 5 O).

Eragrostis japonica

Lemma:

Apex: The cells are long with loosely arranged, irregular undulation and narrow tip followed by the broader region (Figure 4 G).

Middle: The undulation has specific Ω shaped. Long, narrower cells with straight transverse wall (Figure 4 H).

Base: The cells show Ω shaped undulation. The transverse wall is oblique (Figure 4 I).

Palea:

Apex: Undulated wall is compactly arranged. Cell walls are \cap -undulated. The undulations rounded, wider towards the apex and slightly narrower at the base. Most observed oblique wall between two cells (Figure 5 P).

Middle: Undulation is very compactly arranged. The apex is slightly broad and rounded followed by base which is broader. The cells are short in length and broad (Figure 5 Q).

Base: The undulation is Ω shaped. The cells are short in length and broaden in width. Short cell density is very less. Undulation is compactly arranged (Figure 5 R).

Eragrostis nutans

Lemma:

Apex: Long epidermal cells with compact undulation wall with \cap -undulation. The undulations rounded, wider towards the apex and slightly narrower at the base. Most observed oblique wall between two cells but sometimes straight also (Figure 4 J).

Middle: The undulation has Ω shaped. The cells are very long, narrow. Short cells are very less (Figure 4 K).

Base: The undulation is very compactly arranged and highly wavy. Cells are long, narrow. Short cells are less (Figure 4 L).

Palea:

Apex: The epidermal long cell walls are \cap -undulated. The undulations rounded, wider towards the apex and slightly narrower at the base (Figure 6 A).

Middle: Undulation is compactly arranged. Cells are narrower and long. Short cells are very less, very compactly arranged cells which are not vary in length (Figure 6 B).

Base: The undulation is Ω shaped. The cells are short in length and broad. The apex of undulation is less broad (Figure 6 C).

Eragrostis pilosa

Lemma:

Apex: Undulation is compactly arranged. Mostly straight wall are found between the two cells but sometimes oblique also (Figure 4 M).

Middle: Epidermal cells are very thin walled, long and narrow; interrupted by short, rounded cells (Figure 4 N).

Base: The epidermal cells are broad and long. Undulation compactly arranged. The apex is narrow and base is broad (Figure 4 O).

Palea:

Apex: Cells are long and wide. Undulated wall is compactly arranged. The epidermal long cell walls are \cap -undulated. The undulations rounded, wider towards the apex and broad at the base. Most commonly observed oblique wall between two cells. Short cells density less (Figure 6 D).

Middle: The undulation is Ω shaped. Commonly found. The transverse wall between two cells are different either straight or oblique. The transverse wall also shows undulation (Figure 6 E).

Base: The cells are distinctly seen. The undulation wall is straight. The transverse walls between two cells are oblique as well as straight (Figure 6 F).

Eragrostis tenella

Lemma:

Apex: The cells are loosely arranged. Undulation is irregular trichomes interrupt the long cells. Almost straight wall if found between the two cells. Undulation has narrow apex and broader base. Various undulations are seen (Figure 4 P).

Middle: Cells are short, interrupted by unicellular hairs. The undulated walls are not so much coiled. They are irregular and wavy. Cells are long and narrow. The transverse wall is mostly straight and undulated. Cells are very compactly arranged (Figure 4 Q).

Base: The cells are long and irregular undulation. Large number of short cells are present (Figure 4 R).

Palea:

Apex: The epidermal long cell walls are irregularly undulated, narrower at the apex and broad at the base. Straight wall observed between two cells. Short cells are observed between long cells (Figure 6 G).

Middle: Undulation is wavy, irregular type. Cells are long, narrow and short cells are present (Figure 6 H).

Base: The epidermal cells are interrupted by short cells. The cells are long and broad. The transverse walls are both straight as well as oblique. The undulation is very loosely arranged (Figure 6 I).

Eragrostis tremula

Lemma:

Apex: Cells are long and much wider. Undulated wall is loosely arranged, very thick wall is present. Short cells are more in number, more density (Figure 5 A).

Middle: The undulated wall is very thick, interrupted by small, short cells. The cells are broad and the undulation is compactly arranged. The undulation in apex region the narrower followed by broader region (Figure 5 B).

Base: Cells are long and much narrower. Undulated wall is loosely arranged. Short cells are less in number (Figure 5 C).

Palea:

Apex: Cells are long and much wider. Undulated wall is loosely arranged. The epidermal long cell walls are irregularly undulated. The undulations narrower followed by wider region towards the base and further wider at the base. Oblique walls between two cells. Various undulation patterns are observed in this region (Figure 6 J).

Middle: Undulation is very in shapes. Irregular narrow undulation at apex followed by broader region. Cells are broad, short cells are less (Figure 6 K).

Base: Cells are long and much wider. Undulated wall is compactly arranged and very thin. Undulation is Ω shaped which is frequently observed. The transverse wall is almost straight and does not have undulation. Short cells are more in number (Figure 6 L).

Eragrostis uniolooides

Lemma:

Apex: Cells are short and narrow. The end walls of the epidermal cells are folded. Undulated wall is wavy. Most commonly observed straight wall between two cells. Short cells density very less (Figure 5 D).

Middle: The cells show the folded margin at the apex region. This can be a unique feature. The undulation is loosely arranged and having narrower shape at the apex region and broaden towards the basal region. Cells are short, long narrower (Figure 5 E).

Base: Cells are short and narrow. The end walls of the epidermal cells are folded. Undulated wall is loosely arranged. The undulation is wavy type. Presence of straight wall between two cells. Short cells are less in number (Figure 5 F).

Palea:

Apex: Cells are long and much wider. Undulated wall is loosely arranged. The epidermal long cell walls are irregularly undulated. The undulations narrower, followed by wider region towards the base and further wider at the base. Oblique walls between two cells. Various undulation patterns are observed in this region. Short cells are less in number, density is very less (Figure 6 M).

Middle: Cells are various in undulations. Undulation apex sometimes narrow and broad base (Figure 6 N).

Base: Cells are short and broad. The end walls of the epidermal cells are folded but very less seen. Undulated wall is loosely arranged. The undulation is wavy type. Most commonly observed straight wall between two cells. Short cell density is very less (Figure 6 O).

Eragrostis viscosa

Lemma:

Apex: Cells are narrow, long, undulation not compactly folded. Wavy types of undulation present. Short cells are present between the cells (Figure 5 G).

Middle: The undulation is compactly arranged. The cells are Ω shaped. The undulation is very compactly. The apex is slightly narrow and towards the base is broader. The epidermal cells are long and broad. Undulation broader at the apex and broader at the base (Figure 5 H).

Base: The undulation wall is wavy and loosely arranged. Short cells are more (Figure 5 I).

Palea:

Apex: Cells are long and narrow. Undulated wall is compactly arranged. The epidermal long cell walls are \cap -undulated. The undulations rounded, wider towards the apex and slightly narrower at the base. Most commonly observed oblique wall between two cells. Sometimes also seen straight wall too. Various undulation patterns are observed in this region. Short cells are less in number, density is very less (Figure 6 P).

Middle: The cells are compactly arranged. The undulation is Ω shaped, broader at the apex and at the base (Figure 6 Q).

Base: The cells are highly undulated and having Ω shaped undulation. The cells are very long and narrow (Figure 6 R).

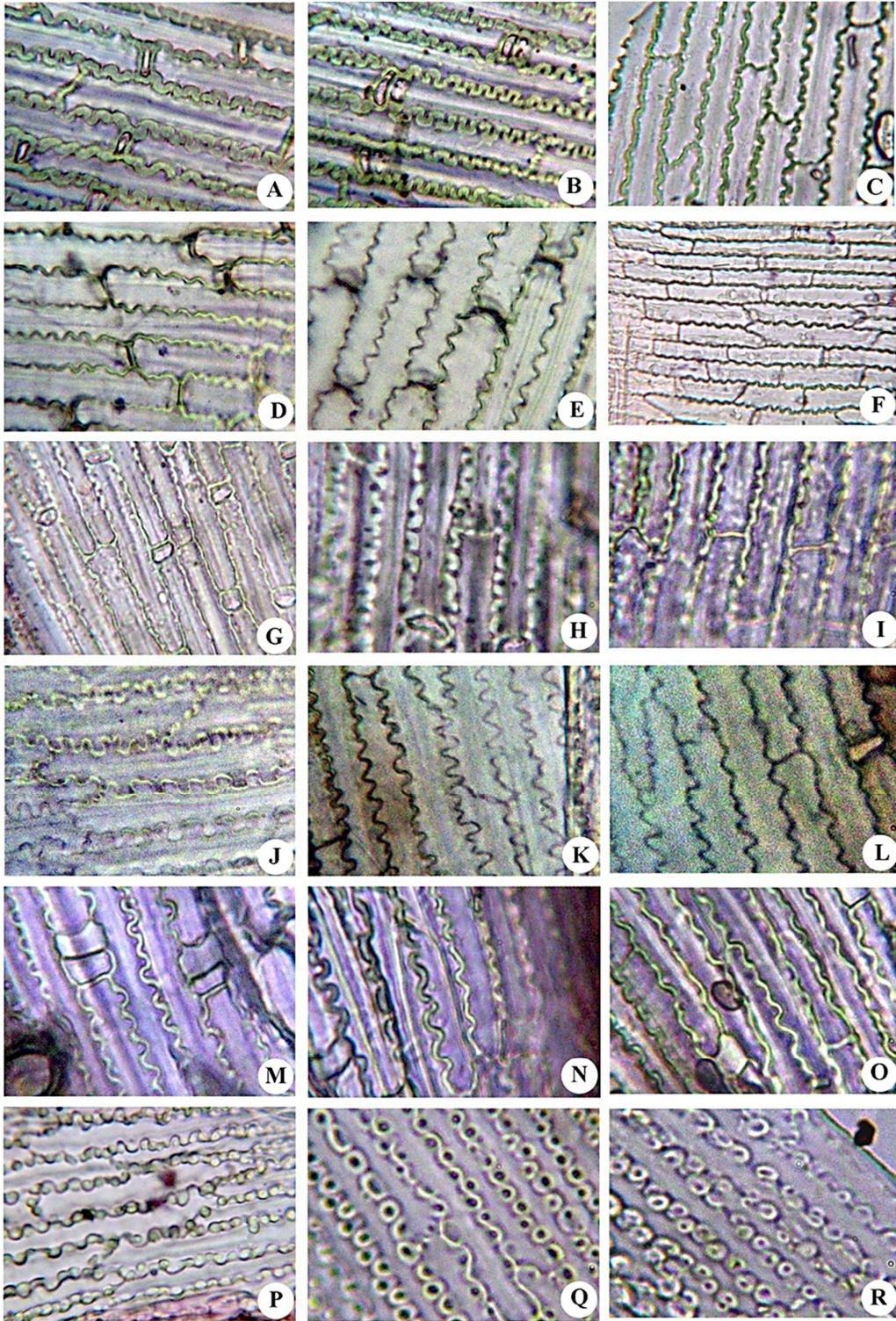


Figure 5. Cells of Lemma and Palea in different species of *Eragrostis*
 A-I: Variations in cells of Lemma in different species of *Eragrostis*; J-R: Variations in cells of Palea in different species of *Eragrostis*; A-C: *Eragrostis tremula*; D-F: *Eragrostis uniolooides*; G-I: *Eragrostis viscosa*; J-L: *Eragrostis cilianensis*; M-O: *Eragrostis ciliaris*; P-R: *Eragrostis japonica*; A, D, G, J, M, P: Cells of apex region; B, E, H, K, N, Q: Cells of middle region; C, F, I, L, O, R: Cells of basal region

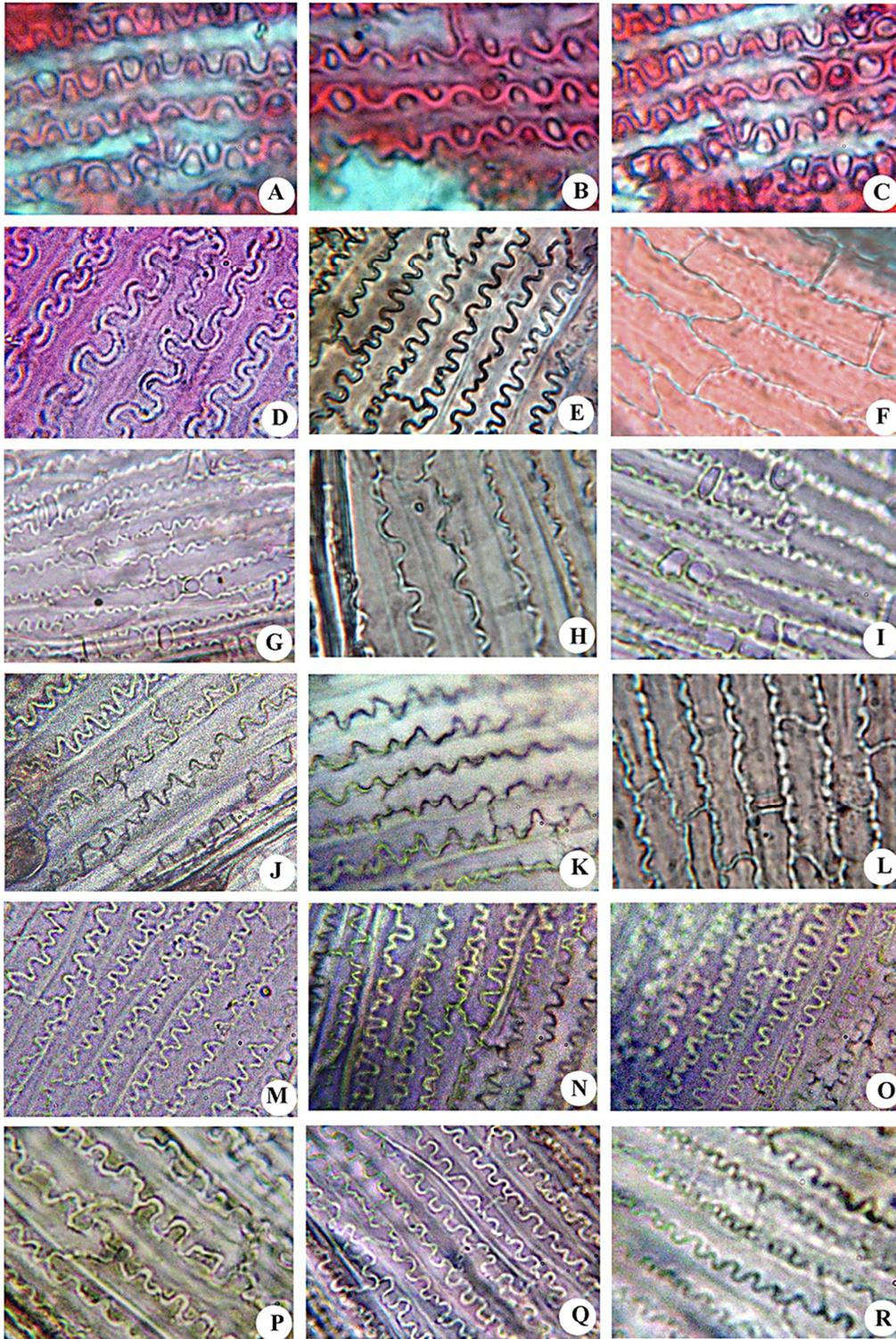


Figure 6. Cells of Palearia in different species of *Eragrostis*
 A-I: Variations in cells of Lemna in different species of *Eragrostis*; A-C: *Eragrostis nutans*; D-F: *Eragrostis pilosa*; G-I: *Eragrostis tenella*; J-L: *Eragrostis tremula*; M-O: *Eragrostis unioides*; P-R: *Eragrostis viscosa*; A, D, G, J, M, P: Cells of apex region; B, E, H, K, N, Q: Cells of middle region; C, F, I, L, O, R: Cells of basal region

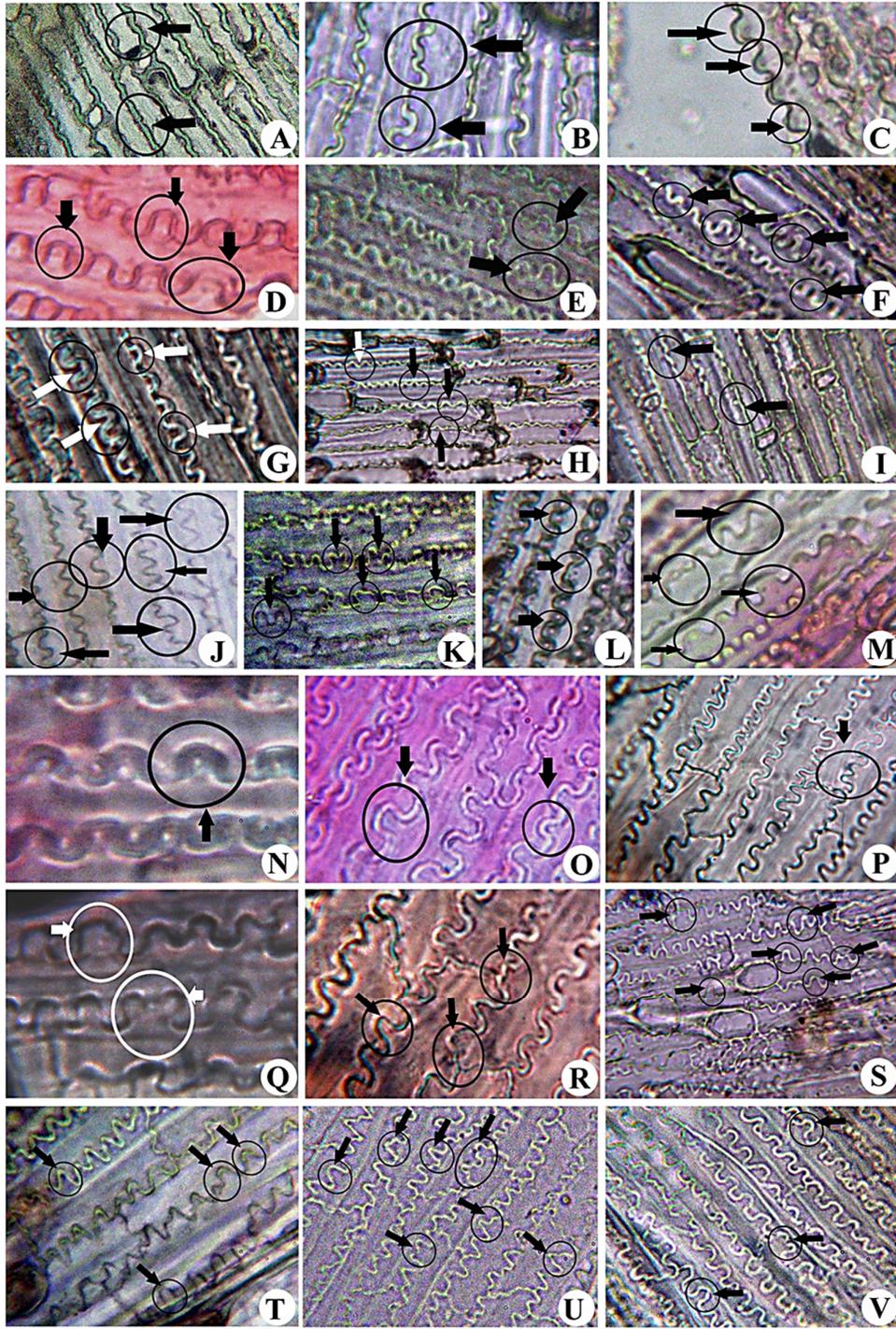


Figure 7. Undulated patterns of epidermal long cells of Lemma and Palea in nine different species of *Eragrostis*

A-I: Undulated patterns of lemma; A: *Eragrostis cilianensis*; B: *Eragrostis ciliaris*; C: *Eragrostis japonica*; D: *Eragrostis nutans*; E: *Eragrostis Pilosa*; F: *Eragrostis tenella*; G: *Eragrostis tremula*; H: *Eragrostis uniolooides*; I: *Eragrostis viscosa*; J-V: Undulated patterns of palea; J: *Eragrostis cilianensis*; K: *Eragrostis ciliaris*; L & M: *Eragrostis japonica*; N: *Eragrostis nutans*; O- R: *Eragrostis Pilosa*; S: *Eragrostis tenella*; T: *Eragrostis tremula*; U: *Eragrostis uniolooides*; V: *Eragrostis viscosa*

Table 1. Comparison of micromorphological characters of Lemma

Name of species	Apex cells (μm)		Middle cells (μm)		Basal cells (μm)		Hairs (μm)		Lemma (μm)	
	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
<i>Eragrostis ciliaris</i>	48.25 \pm 1.59	6.0 \pm 4.02	48.5 \pm 1.5	7.25 \pm 0.2	43.25 \pm 5.97	6.75 \pm 0.09	13.25 \pm 3.11	6.5 \pm 0.2	1143.0 \pm 24.09	739.8 \pm 15.75
<i>Eragrostis ciliaris</i>	44.7 \pm 0.38	7.25 \pm 0.3	42.75 \pm 5.32	5.75 \pm 0.98	54.25 \pm 18.07	9.25 \pm 1.02	155.0 \pm 32.01	10.5 \pm 0.7	4554.0 \pm 39.06	204.0 \pm 21.58
<i>Eragrostis japonica</i>	33.25 \pm 7.55	7.25 \pm 0.44	56.75 \pm 9.34	8.0 \pm 2.06	65.5 \pm 8.24	7.0 \pm 1.84	28.5 \pm 6.83	7.25 \pm 1.97	642.6 \pm 59.03	313.2 \pm 28.78
<i>Eragrostis nutans</i>	39.95 \pm 2.87	6.75 \pm 0.81	47.5 \pm 4.87	6.25 \pm 0.33	57.0 \pm 0.75	5.5 \pm 0.65	39.8 \pm 32.76	6.25 \pm 0.62	553.4 \pm 45.49	316.7 \pm 19.03
<i>Eragrostis pilosa</i>	48.5 \pm 14.98	7.5 \pm 0.42	46.75 \pm 12.84	13.0 \pm 4.38	47.5 \pm 26.8	12.5 \pm 5.56	12.5 \pm 3.26	6.0 \pm 0.66	954.0 \pm 56.42	606.6 \pm 47.48
<i>Eragrostis tenella</i>	56.0 \pm 23.98	8.25 \pm 2.67	43.5 \pm 9.47	8.0 \pm 0.39	60.5 \pm 22.76	7.75 \pm 14.47	16.0 \pm 3.86	6.75 \pm 0.84	720.0 \pm 69.83	423.0 \pm 25.76
<i>Eragrostis tremula</i>	67.0 \pm 19.04	9.75 \pm 2.58	78.75 \pm 9.34	9.5 \pm 0.34	73.75 \pm 25.97	10.25 \pm 2.65	57.75 \pm 12.75	12.75 \pm 2.64	1602.0 \pm 48.38	1191.6 \pm 64.47
<i>Eragrostis unioloides</i>	48.5 \pm 8.37	12.0 \pm 1.89	58.75 \pm 11.98	10.0 \pm 0.97	55.75 \pm 14.87	8.25 \pm 1.86	12.25 \pm 2.40	2.5 \pm 0.076	1943.0 \pm 48.34	837.0 \pm 49.23
<i>Eragrostis viscosa</i>	45.0 \pm 2.09	10.5 \pm 2.56	47.0 \pm 25.42	6.5 \pm 0.12	40.75 \pm 28.87	8.5 \pm 2.15	10.25 \pm 1.74	3.75 \pm 0.64	1009.8 \pm 49.76	644.4 \pm 34.48

Table 2. Comparison of micromorphological characters of Palea

Name of species	Apex cells (μm)		Middle cells (μm)		Basal cells (μm)		Hairs (μm)		Palea (μm)	
	Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
<i>Eragrostis ciliaris</i>	57.8 \pm 12.09	11.4 \pm 4.09	48.1 \pm 4.22	10.9 \pm 0.12	47.3 \pm 9.37	9.8 \pm 1.88	31.6 \pm 7.59	8.6 \pm 1.23	906.2 \pm 48.39	585.9 \pm 12.47
<i>Eragrostis ciliaris</i>	46.5 \pm 8.44	12.75 \pm 2.33	48.25 \pm 21.78	11.0 \pm 1.09	49.25 \pm 10.35	12.0 \pm 0.32	53.50 \pm 10.48	17.0 \pm 1.93	795.6 \pm 28.84	392.4 \pm 32.48
<i>Eragrostis japonica</i>	56.5 \pm 10.47	8.25 \pm 0.39	49.25 \pm 9.21	9.75 \pm 0.04	63.5 \pm 8.24	7.75 \pm 0.08	27.5 \pm 0.34	5.75 \pm 0.32	739.8 \pm 19.49	360.0 \pm 11.83
<i>Eragrostis nutans</i>	47.05 \pm 9.74	7.0 \pm 0.14	48.5 \pm 3.82	4.75 \pm 0.37	52 \pm 5.84	6.25 \pm 0.12	51.7 \pm 5.13	6.5 \pm 0.08	547.8 \pm 37.84	369.5 \pm 25.87
<i>Eragrostis pilosa</i>	52.5 \pm 14.37	7.75 \pm 0.07	47.0 \pm 11.98	12.0 \pm 1.33	56.25 \pm 10.47	9.75 \pm 2.37	22.5 \pm 3.19	6.0 \pm 0.49	790.2 \pm 38.39	340.2 \pm 17.84
<i>Eragrostis tenella</i>	53.75 \pm 13.03	7.75 \pm 0.12	53.0 \pm 11.34	9.25 \pm 0.32	45.25 \pm 9.54	6.75 \pm 1.83	26.00 \pm 8.54	8.5 \pm 0.74	993.0 \pm 37.40	409.0 \pm 54.35
<i>Eragrostis tremula</i>	42.75 \pm 7.23	9.75 \pm 0.23	49.5 \pm 1.87	11.25 \pm 1.32	51.0 \pm 11.59	13.0 \pm 0.14	38.75 \pm 14.74	11.0 \pm 0.16	1330.2 \pm 53.48	750.6 \pm 19.47
<i>Eragrostis unioloides</i>	53.75 \pm 9.84	15.5 \pm 0.94	63.75 \pm 18.33	15.35 \pm 2.73	71.0 \pm 14.75	10.75 \pm 0.11	50.0 \pm 36.34	9.0 \pm 0.64	1740.0 \pm 63.34	975.0 \pm 35.28
<i>Eragrostis viscosa</i>	54.75 \pm 12.48	11.0 \pm 0.78	47.02 \pm 12.78	10.5 \pm 0.13	51.2 \pm 3.37	6.5 \pm 0.05	33.75 \pm 2.49	5.0 \pm 0.95	743.4 \pm 23.48	430.0 \pm 27.32

Variation in undulation patterns

By means of light microscopy the surface undulated patterns of epidermal long cell walls in the lemma and palea can be divided into two distinctly different types as observed in *Setaria* (Houyuan *et al.*, 2009). The epidermal cell walls are having either Ω shaped undulation (undulation rounded, wider towards the apex and narrow at the base) or \cap shaped undulation. Both these types further can produce branching sub ordinate types based on the degree of undulations as Ω I, II, III and \cap I, II, III. The depth and width of the undulations vary in the different studied species depending on which in some the undulations appear very compact, while in some it is scarce as seen very distinctly in the lemma of *E. viscosa* and *E. ciliaris*. All types of undulations seen in Figure 7.

\cap shaped undulation in the palea is very prominent in *E. pilosa*. In the apex and basal region, the undulation is more or less same. It does not become narrow at the base.

This variation observed suggested that the surface undulated patterns of epidermal long cell walls in the lemma and palea can be used to distinguish the different species.

Houyuan *et al.* (2009) divides the ending structures of epidermal long cell into cross wavy type and cross finger type based on characteristics of the dendriform epidermal long cell endings joining others. The average width of endings interdigitation of dendriform epidermal long cells is about $4.37 \pm 0.89 \mu\text{m}$ (N=2774) in cross wavy pattern and in cross finger type, dendriform epidermal long cell endings join others in a deeply digital pattern with average width of the endings interdigitation of dendriform epidermal cells to be longer ($8.95 \pm 2.02 \mu\text{m}$, N= 3303).

Epidermal long cell walls are Ω undulated (undulations rounded, wider toward the apex and narrower at the base) or η undulated. Both these can produce branching subordinate types based on the degree of undulations as Ω I, Ω II, Ω III.

This study shows that species of *Eragrostis* vary in features of spikelet (number, length and degree of overlap), features of glumes (length relative to the upper and lower glume and relative to spikelet length, shapes and apex), number of florets, number of anthers features of lemma and palea (shape, length, width and micromorphology), features of lemmatal awns (length relative to lemma and number), shape of the apex of the distal cell in the microhair. All the variable reproductive morphological characters of the taxa studied are potentially taxonomically informative.

A diagnostic key is prepared based on morphological and micromorphological characters of lemma and palea:

1. Epidermal cells of lemma compactly arranged.....2
1. Epidermal cells of lemma loosely arranged.....4
2. Middle region of lemma epidermal cells do not show specific pattern of undulation.....*E. pilosa*
2. Middle region of lemma epidermal cells shows Ω shaped undulation.....3
3. Apex region of lemma epidermal cells shows \cap shaped undulation.....*E. nutans*
3. Apex region of lemma epidermal cells shows wavy undulation with less compactly folding...*E. viscosa*
4. Basal region of palea epidermal cells shows Ω shaped undulation.....5
4. Basal region of palea epidermal cells shows wavy undulation.....6
5. Middle region of lemma epidermal cells shows Ω shaped undulation.....*E. japonica*
5. Middle region of lemma epidermal cells shows wavy undulation.....*E. tremula*
6. Length of hairs on lemma are $> 100 \mu\text{m}$*E. ciliaris*
6. Length of hairs on lemma are $< 50 \mu\text{m}$7
7. Short cells in basal region of lemma are lesser in number.....*E. unioloides*
7. Short cells in basal region of lemma are more in number.....8
8. Apex region of palea epidermal cells shows \cap shaped undulation.....*E. cilianensis*
8. Apex region of palea epidermal cells shows irregular undulation.....*E. tenella*

Conclusions

Except *E. nutans* all the other species are annuals. The culm in *E. tenella* and *E. unioloides* is strictly geniculating ascending while in *E. nutans*, *E. viscosa*, *E. japonica* and *E. ciliaris* it is erect. In *E. cilianensis*, *E. Pilosa* and *E. tremula* it is erect or geniculating ascending. Inflorescence or spikelets in all the species are dorsiventrally compressed except in *E. ciliaris*. Spikelets of *E. pilosa*, *E. tremula* and *E. unioloides* are prominently laterally compressed while spikelets of *E. japonica*, *E. nutans*, *E. cilianensis*, *E. ciliaris*, *E. viscosa* and *E. tenella* are not compressed. The length and breadth of the spikelet is maximum in *E. tremula* with maximum number of florets (12-36). Spikelets of *E. nutans* invariably has 1 or 2 florets. (Gandhi et al., 2016).

The size of the cells at the apex, middle and base of the lemma varied in a species within the length and width. The length of the lemma was maximum in *E. tremula* and *E. uniolooides* while it was minimum in *E. japonica* and *E. nutans*.

Similarly, size of the cells showed variation in the three different regions (apex, middle and basal) of the pale of the species and within species. The size of palea was maximum in *E. uniolooides* and minimum in *E. nutans*. There was a significant variation in the characteristic features of microhairs.

One of the main problems with micromorphological studies is to determine the optimal site of observation. The lemma shows variations in the expression of micromorphological characters within its apex, base and margins, whereas the palea varies mostly near the apex and in some cases in the wings.

The analysis of the epidermal micromorphology of lemma and palea reveals considerable variation in the nine species of *Eragrostis*. These characters are valuable for systematic studies in Poaceae.

Based on the different micromorphological variation observed in the lemma and palea diagnostic key has been prepared which would facilitate in the identification of the different species.

Authors' Contributions

Both authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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