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Foliar epidermal and trichome micromorphological diversity among poisonous plants and their taxonomic significance

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ABSTRACT

Scanning microscopic imaging has become a valuable research tool in micromorphology with improved techniques playing an important role in analysing the ultrastructure of leaf specimens. The foliar epidermal anatomy of 25 selected poisonous plants with special emphasis on stomata and trichomes was reported using microscopic techniques, for instance, light micrographs (LMs) and scanning micrographs (SEMs). This study aimed to investigate micromorphologies of studied species that are helpful for the identification of poisonous plants. Plants were collected, pressed, dried, identified and then analysed for microscopic study. For making microscopic slides, 1 or 2 leaves were taken in a test tube and dipped in 30% nitric acid and 70% lactic acid for few minutes, and then placed on petri plates for separating the epidermis. Numerous quantitative and qualitative foliar anatomical features of adaxial and abaxial surfaces, including epidermal cell shapes, stomata size, subsidiary cell size, the pattern of the anticlinal wall, the morphology of the stomatal complex and trichome diversity, were examined. A small number of the considered species had anomocytic and anisocytic stomata; a few species had paracytic stomata, for instance, *Ricinus communis, Euphorbia royleana, Buxus pilosula* and *Sorghum halepense*; and only *Ipomoea carnea* had cyclocytic stomata in the studied taxa. The epidermal cells of the analysed species were irregular, while some exhibited polygonal, wavy, tetragonal and elongated cell morphologies. Overall, this study emphasises the significance of foliar micromorphology analysis as a valuable resource for identifying potentially poisonous plants and demonstrates its contribution to maintaining public welfare, thereby benefitting public health and safety.

Keywords: biodiversity, foliar epidermis, microanatomy, stellate trichomes, taxonomy

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INTRODUCTION

Many plants provide us with food, medications, textiles and building materials, while others enhance the beauty of our surroundings. In addition to these beneficial plants, there are several plants that are harmful. Poisonous plants are those that contain compounds capable of causing varying degrees of discomfort, adverse physical and chemical effects, or even death in humans and animals when consumed or otherwise come into touch with the human body (Fuller and Mcclintock, 1986). Poisonous plants contain harmful chemicals in quantities that can cause sickness or demise in animals and humans. The toxic components of these plants can be present in the root, fruit bulb, stem, pollen branch, seed leaf, rhizome, flower, nectar or sap, which may vary from species to species. Plant ingredients such as photosensitising chemicals, minerals, glycosides, oxalates, proteins, terpenes, alkaloids, amino acids, tannins, phytotoxins and phenolics are all toxicologically important and known as secondary metabolites (Konyar et al., 2014). With the accumulation of secondary metabolites in plant parts, it is considered to be poisonous that is deadly to herbivorous animals. Unfortunately, defining poisonous plants is difficult because certain poisonous plants are also regarded as good for the treatment of specific conditions (Sadia et al., 2022).

Plant poisoning in animals is usually unintentional, and it most commonly happens under unfavourable situations such as overstocking, grazing trampling and drought; for example, animals could eat hay that has been infected with deadly weeds. It could be unintentional or intentional in people. Poisoning in humans can occur as a result of mixing poisonous and edible plants, contamination of food with poisonous plants or employing plants as cures. To avoid poisonous plants, it is obligatory to identify them first. In this study, foliar anatomical features are used as an aid to identify poisonous species (Botha and Penrith, 2008).

Similar to medical plants, these species can be further classified depending on the presence of specific compounds in various parts of the plant body, that is, alkaloids, glycosides, tannins, phenols and volatile oils. Some medicinal herbs, on the other hand, have deadly effects on humans when taken in large quantities (Baloch et al., 2017). Many poisonous plants have several functions, and in the right amounts or forms, they can be beneficial. Drugs are also derived from these species, for example, digitalis and morphine. Digitalis is a commonly prescribed cardiac drug that, when administered incorrectly, can be deadly toxic. Important medications such as codeine and morphine are derived from the milky juice of the opium plant. These medicines are intended to treat pain, but when used indiscriminately, they can be harmful and even fatal (Fuller and Mcclintock, 1986). On rare occasions, a hazardous chemical is concentrated in a specific area of the plant. Rhubarb's leaf blade is poisonous, but its petiole is edible. Toxic chemicals are abundant in the fruits and seeds of several plants. When the seeds of castor beans, *Ricinus communis*, are eaten, a very poisonous chemical lectin called toxalbumin is released. Ingesting more than two or three castor bean seeds can result in death. Furthermore, while many plants are used to adorn our surroundings, certain ornamental plants contain hazardous chemicals (Fuller and Mcclintock, 1986).

Many research work has been carried out on the different aspects of the leaf anatomy, but yet no record on the identification of poisonous plants based on their trichomes exists in Pakistan. The importance of anatomical approaches in taxonomic research cannot be overstated. Without microscopic aspects of the epidermal anatomy, taxonomic monographs are incomplete (Abbas et al., 2022; Majeed et al., 2023a). The size and anticlinal wall, the form of stomata, guard cell profile, subsidiary cells and trichome varieties are some of the foliar epidermal traits of high value (Ashfaq et al., 2019). As a result, taxonomists are interested in learning more about the anatomy of the leaf epidermis. The variances in epidermal traits between species may be attributable to genetic differences or the diversity of natural habitats (Hameed et al., 2020). The relevance of micromorphology in the plant nomenclature has long been recognised since variations within a family, genus or species are frequently revealed in anatomical traits (Shahzad et al., 2022; Majeed et al., 2023b).

The taxonomic study using microscopic techniques is used as a tool for micromorphology of foliar epidermal study using LM and SEM. Transmission light is commonly utilised as a light source in light microscopy (Yuan et al., 2020). In past flower inflorescence studies, fruits and leaf external morphologies were used in plant taxonomy, but currently, the leaf anatomy is used for identification purposes. A great number of studies have been undertaken in Pakistan to analyse the leaf epidermis to observe the leaf micromorphology, but no record has been determined yet for the anatomical study of poisonous plants.

The major goals of the current study are to establish the feasibility of utilising foliar anatomical traits to identify poisonous plant species. Prompt identification plays a crucial role in facilitating effective medical interventions, helping to prevent unintentional consumption or contact. By accurately and consistently identifying poisonous plants, authorities and medical practitioners can enhance public safety and protect the public from potential hazards.

MATERIALS AND METHODS

Plant sampling

During the current study, 25 poisonous plant species were collected from various locations in the lower Himalayas between March and September 2021. The collected species were dried, pressed, mounted and labelled. Plant species were identified using herbarium specimens from the Herbarium of Pakistan (ISL) QAU, Islamabad, as well as information from the flora of Pakistan (http://www.eflora.org). The Plant List (TPL) (http://www.theplantlist.org) and the International Plant Names Index (http://www.ipni.org) were used to confirm the plant species. Table 1 lists the names of plant species, voucher number, collector, location and altitude.

Light microscopy for investigating foliar anatomical features

Using a light microscope, fresh leaf samples of 25 poisonous plants were investigated in which trichomes were examined in nine species following the method described by Raza et al. (2020). To keep the leaves from drying out, they were picked from actively developing plants and dipped in water for some time. Then, 1 or 2 leaves were placed in a test tube and dipped in 70% lactic acid and 30% nitric acid for 2 min or until the leaves became translucent. The leaves were then transferred into a cell culture dish, and the translucent sections were rinsed 2–3 times with water. Through a camel hair brush and sharp needle, the epidermal portions from the abaxial and adaxial sides of the sample were meticulously detached. The isolated epidermis was processed with a droplet of lactic acid to clean the section before being placed on a slide by coverslips. To make permanent slides, the margins of coverslips on slides were covered with translucent nail polish. For each plant species, six or seven samples of the abaxial and adaxial surfaces were prepared. A Nikon Microscope with Plan-40X/0.65 lens was used to examine the set slides. Using an XSP-45LCD microscope, the characteristics of the leaf epidermis were photographed. The following characteristics were observed under microscopy: width and length of epidermal cells, stomatal apparatus, trichomes and morphology

Table 1. Collector names, voucher numbers, altitude, locality and district of studied species.

S. No.	Taxa	Collector	Voucher number	Altitude (m)	Locality	District
1	*Agave americana* L.	Aqsa Abid	131601	540	QAU	Islamabad
2	*Alocasia macrorrhizos* (L.) G.Don	Aqsa Abid	131602	508	Rawalpindi	Punjab
3	*Argemone mexicana* L.	Aqsa Abid	131603	540	QAU	Islamabad
4	*Brugmansia versicolor* Lagerh	Sabir Ahmed	131604	540	Capital territory	Islamabad
5	*Butea monosperma* (Lam.) Taub.	Aqsa Abid, Salman	131605	540	QAU colony	Islamabad
6	*Buxus pilosula* Urb	Aqsa Abid	131606	1064	Margalla hills	Islamabad
7	*Chenopodium ambrosioides* L.	Aqsa Abid	131607	508	Rawalpindi	Punjab
8	*Chrozophora tinctoria* (L.) A.Juss.	Aqsa Abid	131608	980	Islamia college Peshawar	KPK
9	*Datura innoxia* Mill.	Aqsa Abid	131609	508	Rawalpindi	Punjab
10	*Duranta erecta* L.	Aqsa Abid	131610	540	Capital territory	Islamabad
11	*Euphorbia helioscopia* L.	Aqsa Abid	131611	508	Dhamial camp	Punjab
12	*Euphorbia pulcherrima* Willd. ex Klotzsch	Aqsa Abid	131612	540	QAU girls hostel	Islamabad
13	*Euphorbia royleana* Boiss	Aqsa Abid	131613	540	QAU	Islamabad
14	*Ipomoea carnea* Jacq.	Aqsa Abid	131614	279	Chakri	Rawalpimdi
15	*Parthenium hysterophorus* L.	Aqsa Abid	131615	482	Dhamial camp	Rawalpindi
16	*Peganum harmala* L.	Aqsa Abid	131616	508	Rawalpindi	Punjab
17	*Physalis angulata* L.	Aqsa Abid	131617	540	QAU	Islamabad
18	*Ranunculus sceleratus* L.	Beenish	131618	165	Dera ismail khan	Punjab
19	*Ricinus communis* L.	Aqsa Abid	131619	482	Dhamial camp	Islamabad
20	*Sambucus nigra* L.	Aqsa Abid	131620	540	QAU	Islamabad
21	*Solanum nigrum* L.	Aqsa Abid	131621	1604	Margalla hills	Islamabad
22	*Solanum incanum* L.	Aqsa Abid	131622	279	Chakri	Rawalpindi
23	*Sorghum halepense* (L.) Pers.	Aqsa Abid	131623	500	Morgah	Rawalpindi
24	*Thevetia peruviana* (Pers.) K.Schum.	Aqsa Abid	131624	540	Capital territory	Islamabad
25	*Trifolium repens* L.	Bushra Ali	131625	2601	Khaplu	Gilgit Baltistan

of the epidermal cell, stomatal complex, the pattern of anticlinal walls (AW), and types of trichomes. Table 2 and Table 3 summarise the qualitative and quantitative characteristics, respectively. Mean (minimum–maximum) ± standard error SE (e.g., 56.7–160 = 89.6 ± 9.5) are used to express quantitative properties. For each abaxial and adaxial surface, five readings of each characteristic were recorded. The quantitative data were analysed using SPSS software IBM, Chicago, USA to calculate the values of mean, maximum, minimum and standard error. These data are extremely useful in identifying species and various epidermal features. These indices include information of length and width of the epidermal cell, subsidiary cells, stomatal complex and trichomes.

Scanning microscopy to investigate trichome diversity

For SEM investigation, dried and mature leaves were washed with ethanol to expel the flotsam and jetsam. For slide preparation, the leaf cuttings were placed on stubs with a twofold covered scotch tape. The samples were super-coated with gold-palladium and examined by SEM (Show JEOL-5910, USA) introduced in the Central Library Office of Material Science College of Peshawar. A Polaroid P/N 665 film was used to take pictures. The samples were analysed beneath the magnifying lens and scrutinised the different micromorphological highlights (epidermal cells, trichomes, stomata) of the leaf (Gul et al., 2019).

RESULTS AND DISCUSSION

The present investigation begins by offering a well-structured overview through a critical examination of the literature on poisonous plants from different regions of Islamabad, as discussed in Table 2. According to this review study, the most dominant families were Solanaceae (five species) and Euphorbiaceae (five species).

The present study examined the qualitative and quantitative features of 25 poisonous plant species from various families in Islamabad. The qualitative attributes examined included the appearance of epidermal cells, the pattern of AW, types of stomata and trichome types on both abaxial and adaxial surfaces. Quantitative attributes, such as the size of epidermal cells, stomatal complexes and trichomes, were also measured and shown in a tabular form (Table 3 and Table 4). The light microphotographs of the considered taxa are demonstrated in Figures 1–6, and the scanning micrographs of trichomes of the studied species are demonstrated in Figures 7–9. The dominant families in the current study were Solanaceae (five species), including *Brugmansia versicolor, Datura innoxia, Physalis angulata, Solanum nigrum*, *Solanum incanum* and Euphorbiaceae, which comprises *Chrozophora tinctoria, R. communis*, *Euphorbia royleana, Euphorbia pulcherrima* and *Euphorbia helioscopia,* followed by Fabaceae having two species (*Trifolium repens* and *Butea monosperma*). While rest of the families contains one species each, including Ranunculaceae (*Ranunculus sceleratus*), Apocynaceae (*Thevetia peruviana*), Buxaceae (*Buxus pilosula*), Araceae (*Alocasia* macrorrhiza), Asparagaceae (*Agave Americana*), Poaceae (*Sorghum halepense*), Verbenaceae (*Duranta erecta*), Amaranthaceae (*Chenopodium ambrosioides*), Papaveraceae (*Argemone mexicana*), Convolvulaceae (*Ipomoea carnea*), Nitrariaceae (*Peganum harmala*) and Adoxaceae (*Sambucus nigra*). This study aimed to provide valuable information for the identification of poisonous plants based on their micromorphological features using microscopic techniques.

Quantitative attributes

Leaf epidermal morphology plays a crucial role in plant taxonomy and systematics. The quantitative attributes of leaf epidermal cells were measured in terms of their width and length on both the abaxial and adaxial surfaces. The maximum length of epidermal cells was observed on the lower surface, while the maximum width was observed on the upper surface. For example, *E. helioscopia* had the maximum length of epidermal cells (99.50 ± 9.02 µm) on the adaxial surface, whereas *I. carnea* had the lowest length (29.25 ± 1.31 µm). Similarly, the maximum width of epidermal cells was observed in *S. nigra* (45.05 ± 1.9 µm), while the lowest width was observed in *S. incanum* (12.25 ± 0.35 µm). Subsidiary cells, which are present alongside epidermal cells, also exhibited variations in width and length on both surfaces. *S. halepense* had the maximum length of subsidiary cells (61.9 ± 2.46 µm) on the adaxial surface, while *R. communis* had the lowest length (19.85 ± 1.2 µm). The maximum width of subsidiary cells was observed in *Ranunculus sceleratus* (32.40 ± 2.4 µm), while the minimum width was observed in *E. helioscopia* (7.9 ± 0.36 µm). On the abaxial surface, *A. mexicana* had the highest length of subsidiary cells (60.85 ± 4.02 µm), while *I. carnea* had the shortest length (23.40 ± 0.40 µm). Similarly, the highest width of subsidiary cells was observed in *A. mexicana* (37.95 ± 1.27 µm), while the lowest width was observed in *E. helioscopia* (9.50 ± 0.50 µm).

Variations in the width and length of stomatal pore and guard cells on the abaxial and adaxial sides were also observed in this study. On the adaxial surface, *Alocasia macrorrhizos* had the maximum length of stomata (34.30 ± 0.69 µm), while the minimum length of stomata was observed in *E. Helioscopia* (16.50 ± 1.0 µm). The highest width of stomatal length was observed in *E. Royleana* (29.85 ± 0.69 µm) and the lowest in *E. Helioscopia* (2.75 ± 0.14 µm). On the abaxial side, *S. Nigra* (46.95 ± 1.15 µm) had the maximum length of stomata, while the minimum length of stomata was examined in the following three plants: *S. incanum* (14.15 ± 0.4 µm), *I. carnea* (14.15 ± 0.36 µm) and *B. monosperma* (14.15 ± 0.36 µm). The highest width of stomata was observed in *S. nigra* (34.55 ± 0.64 µm)

Table 2. Comprehensive review study of poisonous plants.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
1.	*Agave americana*	Asparagaceae	Spring, summer, fall winter	Century plant, maguey, or American aloe	Rosette-forming herbaceous perennial succulent	Cultivated	Mexico, United States	Leaves sap/juice	Acrid volatile oil, oxalic acid, saponoside	Redness and swelling, swelling of small blood vessels (veins), skin sores	Ahmad (2012)
2.	*Alocasia macrorrhiza*	Aricaceae	Spring, summer, fall winter	Taro/ elephants ear	Evergreen perennial	Cultivated	Africa, western Asia, eastern Asia, the Pacific Islands, America, the USA, Brazil	Leaves and corms	Calcium oxalate and oxalic acid	Conjunctivitis, pruritus, blindness	Ufelle et al. (2018)
3.	*Argemone mexicana*	Papaveraceae	March, April, May, June	Mexican prickly poppy, flowering thistle	Broadleaved herbaceous, seed propagated	Wild	Central Mexico, Honduras	All parts of plants are poisonous	Sanguinarine, dihydrosanguinarine	Perianal itching, pneumonia myocarditis and congestive cardiac failure, ascites, sarcoid-like skin changes, alopecia, hepatomegaly	Brahmachari et al. (2013)
4.	*Brugmansia versicolor*	Solanaceae	Mid-summer to fall	Angel's trumpets	Broadleaf evergreen	Cultivated	Western part of South America, south of the Gulf of Guayaquil in Ecuador	Flowers, leaves, and seeds	Alkaloids like atropine, scopolamine and hyoscyamine	Intense thirst, dilated pupils, high or low blood pressure, fast heartbeat, convulsions, difficulty breathing, illusions, paralysis, coma, death, nervousness, loss of memory	Petricevich et al. (2020)

Continued

Table 2. Continued.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
5.	*Butea monosperma*	Fabaceae	January to March	Flame-of-the-forest	An erect deciduous tree with young parts hairy	Wild	Sub-tropical and tropical areas of the Indian Subcontinent and Asian southeast region.	All parts especially seeds	Fixed oil in the seed and glucoside butrin of the flower sap	Dizziness, headache, hypotension	Ahmad (2012)
6.	*Chenopodium ambrosioides*	Amaranthaceae	April - January	Mexican tea, Jesuit's tea	Polymorphic annual, and perennial herb	Wild	Native to Central America, South America, and southern Mexico	Leaves	Carvacrol, caryophyllene oxide and ascaridole	Vomiting, dizziness, headache, temporary deafness, kidney and liver damage, convulsions, paralysis, death	Da Silva et al. (2014)
7.	*Chrozophora tinctoria*	Euphorbiaceae	April to June	Dyer's croton, giradol, or turnsole	Erect densely woolly herb	Wild	Mediterranean, Middle East, India, Pakistan, and Central Asia	All parts of plant are poisonous	Rutin, chrozophorin, saponins	Upset stomach, vomiting, nausea, diarrhoea	Al-Snafi (2015)
8.	*Datura inoxia*	Solanaceae	July to frost	Pricklyburr	Shrubby, sprawling, short-lived, tender perennial	Wild	Central America, Texas, Colombia	All portions of the plant are toxic especially foliage and seeds	Alkaloids, hyoscyamine, hyoscine	Enlarged pupils, dry mouth, trouble breathing, blurred vision, hallucinations, panic, death	Ahmad (2012)
9.	*Datura stramonium*	Solanaceae	March through November	Jimsonweed, locoweed, thorn apple, devil's trumpet	Wild-growing herb	Wild	Central America, Caribbean	Seeds and leaves	Alkaloids, hyoscyamine, hyoscine	Blurred vision, dry mouth, dilated pupils, confusion, combative behaviour hallucinations, difficulty urinating	Ahmad (2012)

Continued

Table 2. Continued.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
10.	*Duranta erecta*	Verbenaceae	Spring	Pigeon berry	Erect and spreading	Cultivated	Florida, South America	Leaves, fruit and bark are poisonous	Saponin	Vomiting and gastro-intestinal irritation, diarrhoea	Ahmad (2012)
11.	*Euphorbia helioscopia*	Euphorbiaceae	Mid-spring to late summer, May to October	Wart spurge, umbrella milkweed and madwoman's milk	Erect perennial herb	Wild	Europe, northern Africa, Asia	Leaves	Diterpene 12-deoxypharbol	Nausea, allergic reactions, skin irritation, vomiting	Ahmad (2012)
12.	*Euphorbia heterophyll*a	Euphorbiaceae	September-March	Mexican fireplant, painted euphorbia, wild poinsettia	A small, annual herb, glabrous	Wild	Central & S. USA, America, tropical Africa, Asia, Pacific countries	All fragments of the plant are lethal	Oil, saponins, glycosides	Nausea, allergic reactions, skin irritation, vomiting	Adedapo et al. (2004)
13.	*Euphorbia pulcherrima*	Euphorbiaceae	October to December	Poinsettia	Shrub or small tree	Wild	Mexico, Central America to southern Guatemala	All parts of plant are poisonous	Water soluble caoutchouc	Upset stomach, vomiting, nausea, diarrhoea	Ahmad (2012)
14.	*Euphorbia royleana*	Euphorbiaceae	Spring to early summer (March–July)	Sullu spurge, and Royle's spurge	Deciduous, cactus-like, succulent shrub or small tree	Wild	Himalaya mountains from Pakistan, Nepal to western China India, Bhutan, Myanmar	All parts are poisonous	Epitaraxerol, ellagic acid, euphol, taraxerol, sitosterol in milky latex	Nausea, vomiting	Bhatia et al. (2014)
15.	*Ipomoea carnea*	Convolvulaceae	Fall – summer	Pink morning glory, bush morning glory	Twining plant	Wild	Tropical America, Caribbean, America, Africa, Australia, and Asia	Seeds and leaves	*N*-methyl-trans-4-hydroxy-l-proline, calystegines B1, swainsonine, 2-epilentiginosine and B2, B3 and C1	Abnormal endocrine functions and gastrointestinal functions, immune system alternation, abnormality in embryogenesis	Wanule and Balkhande (2012)

Continued

Table 2. Continued.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
16.	*Nerium oleander*	Apocynaceae	July to October	Oleander or nerium	Erect shrub bearing pink or white flowers	Cultivated	Mediterranean Basin	Entire plant	Cardiac glycosides of the cardenolide type	Weakness, diarrhoea, nausea, vomiting, headache, pain in stomach, death	Ahmad (2012)
17.	*Parthenium hysterophorus*	Asteraceae	March to October	Santa Maria feverfew, whitetop weed	Erect stout undershrubs	Wild	Subtropics of North and South America	All its parts including trichomes and pollen	Parthenin and other phenolic acids	Eczema skin inflammation, hay fever, asthma, burning and blisters, breathlessness and choking, allergic rhinitis, black spots, diarrhoea, severe erythematous eruptions	Ahmad (2012)
18.	*Peganum harmal*a	Nitrariaceae	April and October	Wild rue, Syrian rue, African rue, esfand or espand, or harmel	Perennial, herbaceous plant	Wild	Middle East, Africa, Mediterranean area, Indian Pakistan, Iran, Africa, Central Asian republics semi-arid regions	Leaves and seeds	β-carbolines such as: harmalol, harman harmaline, harmine, and quinazoline derivatives	Hallucinations, neurosensory syndromes, bradycardia, nausea, vomiting	Mahmoudian et al. (2002)

Continued

Table 2. Continued.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
19.	*Physalis angulate*	Solanaceae	Spring/ summer/ autumn	Cut-leaf ground-cherry, angular winter cherry	Multi-stemmed and spreading	Wild	USA, South America, NC	Unripe berries and leaves	Physalins	Headache, discomfort in stomach, dropped temperature, expanded pupils, nausea, diarrhoea, cardiac and breathing depression, loss of consciousness, fatal schistosomiasis	Pomilio et al. (2008)
20.	*Ranunculus sceleratus*	Ranunculaceae	May to September	Celery-leaved buttercup	Annual or short-lived perennial	Wild	Europe, Britain, primarily in central and northern areas	All parts of the plant are poisonous	Glycoside ranunculin	Enormously annoying to skin and mucous membranes. It may cause pain and burning perceptions, tongue inflammation, and intensification in saliva	Ahmad (2012)

Continued

Table 2. Continued.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
21.	*Ricinus communis*	Euphorbiaceae	June to October	Castor oil plant	Tender perennial large shrub or small tree	Wild	Southeastern Basin, India Mediterranean, Eastern Africa	Seeds and leaves	Toxalbumin ricin	Nausea, sickness, diarrhoea, abdominal pain, desiccation, shock, simple fluid and chemical disturbances, destruction to the liver, kidney and pancreas, and eventually death	Ahmad (2012)
22.	*Solanum incanum*	Solanaceae	October–January	Thorn apple, bitter apple, bitterball and bitter tomato	An erect prickly shrub, stem prickly and prickles straight sharp	Wild	Saharan desert in Africa, Middle East, India	Dried unripe fruits	Glycoalkaloids such as solasonine, alkylamines such as nitrosamines and carcinogenic glycosides	Stomach pain, vomiting, diarrhoea	Madzimure et al. (2013)
23.	*Solanum nigrum*	Solanaceae	July to September	Black nightshade or blackberry nightshade	Short-lived perennial shrub	Wild	South America	Fruits, leaves	Steroidal glycoalkaloids like alpha-solanine and alpha-chaconine	Stomach pain, vomiting, diarrhoea	Jabamalairaj et al. (2019)

Continued

Table 2. Continued.

Sr. No.	Plant species	Family	Flowering period	Common name	Habit	Status	Global distribution	Poisonous part	Poisonous compounds	Side effects	Citation
24.	*Sorghum halepense*	Poaceae	Fall to summer	Johnsongrass	Arching dense erect spreading	Wild	Eastern, Mediteranean, Middle East countries	Leaves	Dhurrin, a cyanogenic glycoside, toxic levels of nitrates	Nervousness, progressive feebleness and difficulty breathing, breathlessness, increased pulse rate, muscular jerking, convulsions, death	Khan et al. (2018)
25.	*Thevetia peruviana*	Apocynaceae	Summer to fall	Luckynut, yellow oleander	Perennial or evergreen tropical shrub	Cultivated	Mexico, tropical South America	All parts of the plant are poisonous, especially the kernels of the fruits and leaves	Glycosides, thevetin, cerebrin, neriifolin	Sickness, dizziness, electrolyte turbulences, cardiac dysrhythmias	Ahmad (2012)
26.	*Trifolium repens*	Fabaceae	Spring – summer	White clover	Creeping, prostrate	Wild	Europe, British Isles, central Asia	Leaves	Eyanogenic glucosides linamarin and lotaustralin	Outbreaks, muscle ache, pain, sickness, and vaginal flow (spotting)	Refsgaard et al. (2010)
27.	*Xanthium strumarium*	Asteraceae	Fall to summer	Clotbur, common cocklebur, woolgarie bur	Erect, ground cover herb	Wild	North America	Leaves and seeds	Carboxyatractyloside	Sickness, muscular tremors, liver disintegration and seldom death	Ahmad (2012)

NC, North Canada.

Table 3. Qualitative foliar anatomical features of poisonous plants.

Plant species	Ad × Ab	ECS	AW	Stomata (P/A)	ST	GCS	Glands P/A	SPS	Trichome	
									Glandular	Non-glandular
Chrozophora tinctoria	Ad	Irregular	Deeply sinous	P	Anisocytic	Broad bean-shaped	A	Narrow elliptical	-	Sessile stellate
	Ab	Irregular	Deeply sinous	P	Anisocytic	Broad bean-shaped	A	Narrow elliptical	-	Sessile stellate
Buxus pilosula	Ad	Polygonal	Straight	A	-		A	Very narrowly elliptical	-	-
	Ab	Polygonal	Straight	P	Paracytic	Broad bean-shaped	A	Very narrowly elliptical	-	-
Parthenium hysterophorus	Ad	Irregular	Sinuate	P	Anomocytic	Broad bean-shaped	P	Elliptical	-	
	Ab	Irregular	Sinuate	P	Anomocytic	Broad bean-shaped	P	Elliptical	-	Segmented with pointed tip and broad base
Datura innoxia	Ad	Irregular	Deeply undulate	P	Anisocytic anomocytic	Broad bean-shaped	A	Widely elliptical	-	Multicellular with pointed tip and broad base
	Ab	Polygonal	Straight	P	Anomocytic	Broad bean-shaped	A	Widely elliptical	-	Multicellular with pointed tip and broad base
Ricinus communis	Ad	Polygonal	Straight/angular	P	Paracytic	Broad bean-shaped		Elliptical	-	-
	Ab	Polygonal	Straight	P	Paracytic	Broad bean-shaped	A	Elliptical	-	-
Alocasia macrorrhizos	Ad	Polygonal	Straight	A			A		-	-
	Ab	Polygonal	Straight	P	Paracytic	Broad bean-shaped	A	Broad elliptical	-	-
Euphorbia royleana	Ad	Polygonal	Straight	A	-	-	A	-	-	-
	Ab	Polygonal	Straight	P	Paracytic	Broad bean-shaped	A	Very broad elliptical	-	-

Continued

Table 3. Continued.

Plant species	Ad × Ab	ECS	AW	Stomata (P/A)	ST	GCS	Glands P/A	SPS	Trichome	
									Glandular	Non-glandular
Ranunculus sceleratus	Ad	Irregular	Wavy to sinous	P	Anomocytic	Bean-shaped	A	Elliptical	-	-
	Ab	Irregular	Wavy to sinous	P	Anomocytic	Bean-shaped	A	Elliptical	-	-
*Thevetia peruvian*a	Ad	Irregular	Undulate	A	-	Broad bean-shaped	A	Widely elliptical	-	-
	Ab	Polygonal	Straight/wavy	P	Anisocytic	Broad bean-shaped	A	Widely elliptical	-	-
Agave americana	Ad	Polygonal	Straight	P	Paracytic	Narrow bean-shaped	A	Concave-shaped	-	-
	Ab	Polygonal	Straight	P	Paracytic	Narrow bean-shaped	A	Concave-shaped	-	-
*Brugmansia versicolo*r	Ad	Polygonal	Straight/angular	P	Anisocytic	Broad bean-shaped	A	Elliptical	-	Multicellular with pointed tip and broad base unicellular with bulbous tip
	Ab	Irregular	Undulate/sinous	P	Anomocytic	Broad bean-shaped	A	Widely elliptical	-	Multicellular with pointed tip and broad base unicellular with bulbous tip
Sorghum halepense	Ad	Rectangular	Thick sinous walls	P	Paracytic	Dumb bell-shaped	A	Very narrow elliptical	-	-
	Ab	Rectangular	Thick sinous walls	P	Paracytic	Dumb bell-shaped	A	Very narrow elliptical	-	-
Duranta repens	Ad	Polygonal	Straight	A	-	-	P	-	-	-
	Ab	Polygonal	Straight	P	Anisocytic	Broad bean-shaped	P	Widely elliptical	-	Unicellular with pointed tip
Physalis angulata	Ad	Irregular	Deeply sinous	P	Anomocytic	Broad bean-shaped	A	Narrow elliptical	-	-
	Ab	Irregular	Deeply sinous	P	Anomocytic	Broad bean-shaped	A	Narrow elliptical	-	-

Continued

Table 3. Continued.

Plant species	Ad × Ab	ECS	AW	Stomata (P/A)	ST	GCS	Glands P/A	SPS	Trichome	
									Glandular	Non-glandular
Chenopodium ambrosioides	Ad	Polygonal	Angular	P	Anomocytic	Narrow kidney-shaped	P	Wide elliptical	Multicellular capitate	-
	Ab	Irregular	Wavy	P	Anisocytic	Wide kidney-shaped	P	Elliptical	Multicellular capitate	-
Trifolium repens	Ad	Irregular	Sinous	P	Anomocytic	Broad bean-shaped	A	Elliptical	-	-
	Ab	Polygonal	Straight/angular	P	Anisocytic	Broad bean-shaped	A	Narrow elliptical	Multicellular capitate	-
Solanum nigrum	Ad	Polygonal	Straight	P	Anisocytic	Broad bean-shaped	A	Narrow elliptical	-	Multicellular 3–6 celled long with pointed tip
	Ab	Irregular	Undulate	P	Anomocytic	Broad bean-shaped	A	Elliptical	-	Multicellular 3–6 celled long with pointed tip
Butea monosperma	Ad	Polygonal	Angular	A	-	-	A	Elliptical	-	-
	Ab	Irregular	Wavy	P	Paracytic	Narrow bean-shaped	p	Very narrow elliptical	-	Unicellular with pointed tip
Argemone mexicana	Ad	Polygonal	Angular	P	Anomocytic	Broad bean-shaped		Narrow elliptical	-	-
	Ab	Heptagonal	Angular	P	Anomocytic	Broad bean-shaped	A	Very narrow elliptical	-	-
Peganum harmala	Ad	Polygonal	Straight	P	Anomocytic	Broad bean-shaped	A	Wide elliptical	-	-
	Ab	Polygonal	Straight	P	Anomocytic	Broad bean-shaped	A	Wide elliptical	-	-
Solanum incanum	Ad	Rectangular	Straight	P	Anisocytic	Widely bean-shaped	A	Narrow elliptical		Stellate unicellular with pointed tip
	Ab	Polygonal	Angular	P	Anisocytic	Widely bean-shaped	A	Narrow elliptical		Stellate unicellular with pointed tip

Continued

Table 3. Continued.

Plant species	Ad × Ab	ECS	AW	Stomata (P/A)	ST	GCS	Glands P/A	SPS	Trichome	
									Glandular	Non-glandular
Euphorbia helioscopia	Ad	Polygonal	Straight	A	-	-	A	-	-	-
	Ab	Polygonal	Straight	P	Anomocytic	Broad bean-shaped	A	Narrow elliptical	-	-
Euphorbia pulcherrima	Ad	Irregular	Undulate	A	-	-	A	-	-	Multicellular with pointed end
	Ab	Irregular	Undulate	P	Anomocytic	Broad bean-shaped	A	Narrow elliptical	-	Multicellular with pointed end
Ipomoea carnea	Ad	Rectangular to isodiametric	Straight	P	Cyclocytic	Broad bean-shaped		Very broad elliptical	Subsessile, capitate having 5–6 celled with a flat head	Unicellular and conical-shaped
	Ab	Irregular/ tetragonal	Straight/sinous	P	Cyclocytic/ paracytic	Broad bean-shaped	A	Very broad elliptical	Sub sessile, capitate having 5–6 celled a with flat head	Unicellular and conical-shaped
Ipomoea carnea	Ad	Polygonal	Straight/angular	A			A			-
	Ab	Polygonal	Straight	P	Anomocytic	Broad bean-shaped	A	Wide elliptical	Multicellular with bulbous head	-

Ab, abaxial; Ad, adaxial; AW, anticlinal walls; ECS, epidermal cells shape; GCS, guard cells shape; SPS, stomatal pore shape; ST, stomatal type.

Table 4. Quantitative attributes of studied species.

Plant name	Ad × Ab	Length of epidermal cell Mean (Min–Max) ± SE (μm)	Width of epidermal cell Mean (Min–Max) ± SE (μm)	Length of guard cells Mean (Min–Max) ± SE (μm)	Width of guard cells Mean (Min–Max) ± SE (μm)	Length of stomata Mean (Min–Max) ± SE (μm)	Width of stomata Mean (Min–Max) ± SE (μm)	Length of subsidiary cell Mean (Min–Max) ± SE (μm)	Width of subsidiary cell Mean (Min-Max) ± SE(μm)	Length of stomatal pore Mean (Min–Max) ± SE (μm)	Width of stomatal pore Mean (Min–Max) ± SE (μm)	Trichome length Mean (Min–Max) ± SE (μm)	Trichome width Mean (Min–Max) ± SE (μm)
Agave americana	Ad	69.95 (58.75–81.25) ± 3.97	24.65 (23.75–23.75) ± 0.37	20.0 (17.75–22.0) ± 0.78	6.90 (6.25–7.75) ± 0.29	27.45 (25.25–29.75) ± 0.81	11.35 (10.25–12.75) ± 0.50	52.50 (43.75–63.75) ± 3.29	16.15 (12.75–21.25) ± 1.65	17.30 (16.25–18.75) ± 0.45	1.55 (1.0–2.25) ± 0.242	Absent	Absent
	Ab	63.35 (53.75–81.25) ± 4.75	28.30 (26.25–30.25) ± 0.77	21.05 (20.25–21.75) ± 0.25	5.85 (4.75–7.25) ± 0.43	24.30 (18.75–27.75) ± 1.77	13.15 (11.25–14.75) ± 0.65	50.55 (43.75–54.75) ± 2.14	25.35 (24.0–26.50) ± 0.46	19.40 (18.0–20.25) ± 0.44	0.90 (0.50–1.25) ± 0.16	Absent	Absent
Argemone mexicana	Ad	65.75 (50.25–73.25) ± 4.1	34.50 (32.25–37.25) ± 0.96	32.30 (31.25–34.0) ± 0.51	12.55 (10.25–13.75) ± 0.64	32.95 (31.25–34.75) ± 0.60	26.55 (22.75–29.75) ± 1.39	54.50 (50.25–57.75) ± 1.23	26.45 (22.25–31.25) ± 1.50	20.95 (18.75–22.75) ± 0.75	6.25 (5.25–7.25) ± 0.35	Absent	Absent
	Ab	57.95 (54.75–61.25) ± 1.05	41.85 (27.25–47.25) ± 3.6	27.20 (22.75–32.0) ± 1.7	12.45 (11.25–14.75) ± 0.64	30.55 (27.75–32.75) ± 0.98	27.05 (23.75–29.75) ± 1.17	60.85 (51.75–74.75) ± 4.02	37.95 (34.75–41.25) ± 1.27	22.05 (20.25–23.75) ± 0.60	7.05 (5,25–8.75) ± 0.60	Absent	Absent
Brugmansia versicolor	Ad	42.25 (36.25–51.25) ± 2.55	36.25 (32.75–41.25) ± 1.51	32.05 (30.25–33.75) ± 0.60	10.45 (8.75––12.25) ±0.60	32.30 (31.25–33.75) ± 0.45	28.15 (26.25–29.75) ± 0.62	45.55 (38.75–53.25) ±2.69	29.55 (27.75–31.25) ± 0.60	19.55 (17.75–21.25) ± 0.60	6.85 (3.75–9.75) ± 1.14	356.8 (341.25–375.25) ± 6.1	46.40 (41.25–52.25) ± 1.93
	Ab	39.30 (36.25–46.50) ± 1.84	33.75 (30.25–36.25) ± 1.34	27.95 (26.25–29.75) ± 0.60	10.90 (9.50–12.25) ± 0.54	27.95 (26.25–29.75) ± 0.60	25.15 (23.75–26.25) ± 0.43	47.40 (45.75–48.75) ± 0.55	32.30 (31.25–33.75) ± 0.45	19.70 (18.75–20.75) ± 0.37	8.10 (6.25–9.50) ± 0.58	307.35 (300.75–316.25) ± 2.62	25.55 (23.75–27.75) ± 0.68
Butea monosperma	Ab	30.95 (26.25–38.75) ± 2.11	14.65 (11.25–18.25) ± 1.1	14.15 (13.25–15.25) ± 0.36	6.75 (5.75–7.75) ± 0.35	14.15 (13.25–15.25) ± 0.36	10.7 (7.75–13.75) ± 1.14	23.40 (22.25–24.50) ± 0.40	9.70 (8.75–10.50) ± 0.32	8.95 (7.75–10.25) ± 0.40	4.35 (3.75–5.25) ± 0.29	168.3 (148.75–183.75) ± 6.07	11.25 (8.75–13.75) ± 0.92
	Ad	30.75 (28.75–33.75) ± 0.85	21.10 (18.75–23.75) ± 0.96	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	225.9 (212.75–234.0) ± 3.8	15.35 (13.75–17.25) ± 0.57
Buxus pilosula	Ad	55.45 (52.75–57.75) ± 0.96	40.0 (37.75–42.0) ± 0.78	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	Ab	45.15 (37.75–56.25) ± 3.79	29.65 (26.25–32.75) ± 1.07	25.25 (23.75–27.75) ± 0.77	4.30 (3.0–5.25) ± 0.40	25.25 (23.75–27.75) ± 0.77	12.85 (11.25–14.25) ± 0.53	39.70 (35.75–46.25) ± 1.91	9.95 (8.75–11.25) ± 0.40	21.65 (20.25–23.25) ± 0.57	3.95 (2.75–5.25) ± 0.46	Absent	Absent
Chenopodium ambrosioides	Ad	50.70 (48.0–53.25) ± 1.00	26.55 (24.75–28.75) ± 0.75	24.15 (22.75–25.75) ± 0.50	9.35 (8.50–10.25) ± 0.30	24.25 (22.75–25.25) ± 0.44	19.45 (17.75–20.75) ± 0.53	28.75 (25.25–32.25) ± 1.36	26.35 (23.75–30.25) ± 1.16	15.85 (14.75–17.25) ± 0.43	7.35 (6.25–8.75) ± 0.43	66.05 (63.75–67.75) ± 0.76	20.85 (17.75–23.75) ± 1.06
	Ab	75.05 (72.75–77.25) ± 0.81	28.05 (26.25–30.25) ± 0.68	20.45 (18.75–22.25) ± 0.60	8.55 (7.25–9.75) ± 0.46	21.25 (19.75–22.75) ± 0.57	18.95 (17.75–22.75) ± 0.57	44.75 (42.75–47.25) ± 0.75	18.45 (16.25–22.0) ± 1.01	14.30 (12.0–15.75) ± 0.66	8.05 (6.25–10.25) ± 0.68	57.70 (52.25–64.0) ±2.28	26.25 (24.75–27.75) ± 0.57
Chrozophora tinctoria	Ad	45.25 (38.75–57.25) ± 3.21	23.0 (21.225–24.75) ± 0.60	32.05 (30.25–33.75) ± 0.60	9.85 (8.75–11.25) ± 0.43	32.25 (30.25–33.75) ± 0.68	20.4 (18.75–22.0) ± 0.56	44.0 (37.75–52.25) ± 2.51	15.45 (13.75–17.25) ± 0.60	17.0 (15.25–18.75) ± 0.60	4.8 (3.75–5.75) ± 0.33	226.2 (214.0–248.7) ± 6.01	10.45 (7.25–12.75) ± 1.05
	Ab	48.4 (43.75–56.25) ± 2.10	18.25 (13.75–23.75) ± 1.7	33.25 (31.25–35.25) ± 0.75	7.55 (6.25–8.75) ± 0.40	32.95 (30.25–35.25) ± 0.94	20.55 (18.75–22.25) ± 0.60	41.0 (35.25–48.75) ± 2.72	19.35 (17.75–21.25) ± 0.62	15.49 (13.75–17.25) ± 0.58	3.80 (3.0–4.75) ± 0.36	182.4 (143.75–218.75) ± 16.0	9.95 (8.75–11.25) ± 0.40
Alocasia macrorrhizos	Ad	57.05 (50.25–65.25) ± 2.83	26.95 (25.25–28.25) ± 0.53	34.60 (32.75–36.50) ± 0.64	12.15 (10.75–13.75) ± 0.53	34.30 (32.75–36.50) ± 0.69	26.60 (24.75–28.75) ± 0.77	32.55 (30.75–34.75) ± 0.75	10.15 (8.75–11.50) ± 0.51	22.55 (21.25–24.25) ± 0.62	6.15 (5.25–7.25) ± 0.40	Absent	Absent
	Ab	52.95 (50.25–56.25) ± 1.04	37.05 (35.25–38.75) ± 0.60	34.55 (32.75–36.25) ± 0.60	10.25 (8.75–13.75) ± 0.92	35.05 (32.75–37.25) ± 0.81	27.15 (25.75–28.75) ± 0.53	28.10 (27.75–29.0) ± 0.33	20.45 (16.25–24.75) ± 1.49	21.65 (20.25–22.75) ± 0.43	8.25 (6.25–11.25) ± 0.85	Absent	Absent

Continued

Table 4. Continued.

Plant name	Ad × Ab	Length of epidermal cell Mean (Min–Max) ± SE (µm)	Width of epidermal cell Mean (Min–Max) ± SE (µm)	Length of guard cells Mean (Min–Max) ± SE (µm)	Width of guard cells Mean (Min–Max) ± SE (µm)	Length of stomata Mean (Min–Max) ± SE (µm)	Width of stomata Mean (Min–Max) ± SE (µm)	Length of subsidiary cell Mean (Min–Max) ± SE (µm)	Width of subsidiary cell Mean (Min–Max) ± SE(µm)	Length of stomatal pore Mean (Min–Max) ± SE (µm)	Width of stomatal pore Mean (Min–Max) ± SE (µm)	Trichome length Mean (Min–Max) ± SE (µm)	Trichome width Mean (Min–Max) ± SE (µm)
Datura innoxia	Ad	50.55 (48.75–52.75) ± 0.68	22.75 (21.25–24.75) ± 0.68	22.45 (20.25–24.75) ± 0.81	6.80 (5.25–8.0) ± 0.50	23.85 (20.25–26.25) ±0.99	17.55 (15.25–19.75) ±0.81	38.35 (28.75–44.75) ± 2.90	14.95 (12.25–17.75) ± 0.95	12.95 (12.25–13.75) ± 0.25	6.65 (5.25–7.75) ± 0.43	211.8 (191.25–248.75) ± 10.3	16.05 (13.75–18.75) ± 0.93
	Ab	48.05 (45.25–50.25) ± 0.98	20.55 (18.75–22.75) ± 0.68	24.10 (22.75–25.25) ± 0.43	6.90 (6.25–7.75) ± 0.26	23.95 (22.75–25.25) ±0.46	18.35 (17.25–19.75) ±0.43	29.55 (28.75–30.25) ± 0.25	24.50 (22.25–26.25) ± 0.67	14.85 (13.75–15.75) ± 0.33	5.60 (4.75–6.25) ± 0.29	235.0 (228.75–243.75) ± 2.7	22.55 (20.25–25.25) ± 0.88
Duranta repens	Ab	47.0 (44.50–48.75) ± 0.75	19.70 (18.75–20.75) ± 0.34	28.15 (27.25–28.75) ± 0.29	8.15 (7.25–8.75) ± 0.29	29.15 (27.75–31.25) ± 0.62	22.35 (21.25–23.75) ± 0.43	29.45 (28.0–30.50) ± 0.47	22.35 (21.25–23.75) ± 0.43	15.05 (14.25–16.25) ± 0.33	9.85 (8.75–11.25) ± 0.43	150.9 (143.75–158.75) ± 2.53	17.05 (14.75–18.75) ± 0.71
	Ad	32.65 (24.75–40.25) ± 3.17	14.35 (13.75–15.25) ± 0.29	23.35 (21.25–24.75) ± 0.69	6.60 (5.25–7.75) ± 0.43	23.35 (21.25–24.75) ± 0.69	17.05 (16.25–17.75) ± 0.25	28.75 (26.25–31.25) ± 0.92	10.95 (8.75–12.75) ± 0.75	12.25 (11.25–12.75) ± 0.27	4.40 (3.75–5.25) ± 0.26	159.2 (154.0–162.75) ± 1.64	16.1 (14.0–18.25) ± 0.71
Euphorbia helioscopia	Ad	99.50 (75.5–125.1) ± 9.02	36.50 (35.1–37.3) ± 0.61	27.5 (25.1–27.50) ± 0.50	19.50 (17.50–20.1) ± 0.50	16.50 (12.50–17.50) ± 1.0	2.75 (2.50–3.1) ± 0.14	27.5 (25.1–27.50) ± 0.50	7.9 (7.50–8.25) ± 0.36	41.1 (25.1–52.1) ± 4.8	16.50 (17.50–25.1) ± 1.0	895.2 (750.2–1100) ± 70	11.85 (10.1–13.1) ± 1.21
	Ab	84.50 (75.1–87.50) ± 2.42	36.50 (35.1–40.3) ± 1.0	26.1 (25.1–27.50) ± 0.61	20.25 (18.75–22.50) ± 0.61	17.50 (15.1–20.3) ± 0.79	2.65 (2.50–3.1) ± 0.11	26.50 (25.1–27.50) ± 0.61	9.50 (7.50–10.1) ± 0.50	39.1 (35.1–50.1) ± 2.80	18.50 (17.50–20.1) ± 0.61	Absent	Absent
Euphorbia pulcherrima	Ad	35.30 (33.75–37.25) ± 0.66	20.05 (18.25–21.75) ± 0.68	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	249.9 (238.2–262.7) ± 4.1	19.55 (17.75–21.25) ± 0.60
	Ab	34.55 (32.75–36.25) ± 0.60	19.55 (17.75–21.25) ± 0.60	23.95 (22.75–25.25) ± 0.46	8.05 (7.25–9.25) ±0.40	24.55 (22.75–26.25) ± 0.60	14.05 (12.75–15.25) ± 0.43	33.86 (32.75–34.75) ± 0.33	24.55 (22.75–26.25) ± 0.60	16.25 (15.25–17.25) ± 0.35	3.50 (2.75–4.25) ± 0.27	166.5 (160.25–173.25) ± 2.6	14.75 (12.75–16.25) ± 0.68
Euphorbia royleana	Ad	46.45 (43.75–52.25) ± 1.50	37.15 (33.75–39.75) ± 1.04	33.45 (30.75–36.25) ± 1.07	9.80 (8.75–10.50) ±0.30	33.75 (31.25–36.25) ± 0.92	29.85 (27.75–31.25) ± 0.69	57.30 (53.75–61.25) ± 1.48	31.15 (26.25–39.75) ± 2.29	22.30 (20.25–25.25) ± 0.88	7.05 (5.25–8.75) ± 0.60	Absent	Absent
	Ab	41.85 (38.75–43.75) ± 0.88	30.80 (27.75–34.75) ± 1.23	32.05 (30.25–33.75) ± 0.60	10.15 (8.75–11.25) ± 0.43	31.95 (30.25–33.25) ± 0.53	26.45 (25.25–27.75) ± 0.46	50.95 (48.75–53.25) ± 0.86	24.90 (21.25–29.75) ± 1.40	22.95 (21.25–24.75) ± 0.60	7.85 (7.0–8.75) ± 0.34	Absent	Absent
Ipomoea carnea	Ad	29.25 (26.25–33.75) ± 1.31	25.45 (23.75–27.25) ± 0.60	24.15 (22.25–27.75) ± 1.01	10.45 (9.75–11.25) ± 0.25	26.15 (22.75–28.75) ± 1.04	21.65 (20.25–22.75) ± 0.43	23.45 (7.75–35.25) ± 5.96	9.50 (8.75–10.25) ± 0.27	19.55 (17.75–21.25) ± 0.60	10.05 (7.75–12.25) ± 0.81	39.55 (37.75–41.25) ± 0.60	12.95 (9.75–17.75) ± 1.43
	Ab	30.95 (26.25–38.75) ± 2.11	14.65 (11.25–18.25) ± 1.13	14.15 (13.25–15.25) ± 0.36	6.75 (5.75–7.75) ± 0.35	14.15 (13.25–15.25) ± 0.36	10.70 (7.75–13.75) ± 1.14	23.40 (22.25–24.50) ± 0.40	9.70 (8.75–10.50) ± 0.32	8.95 (7.75–10.25) ± 0.40	4.35 (3.75–5.25) ± 0.29	168.3 (148.75–183.75) ± 6.0	11.25 (8.75–13.75) ± 0.92
Parthenium hysterophorus	Ad	33.95 (26.25–41.25) ± 2.4	15.50 (13.75–18.75) ± 0.92	24.15 (23.25–25.25) ± 0.36	7.10 (6.25–8.0) ± 0.34	24.05 (22.75–25.25) ± 0.43	16.4 (15.25–17.75) ± 0.48	28.75 (24.50–32.75) ± 1.52	18.95 (15.75–23.75) ± 1.45	18.1 (16.25–19.75) ± 0.67	4.95 (3.75–6.25) ± 0.40	165.4 (153.7–173.2) ± 3.70	29.74 (28.13–32.64) ± 0.68
	Ab	38.95 (36.50–43.75) ±1.30	18.35 (16.25–21.25) ± 0.84	19.95 (18.25–21.25) ± 0.62	7.95 (6.25–9.50) ± 0.56	20.35 (18.25–22.25) ± 0.78	18.10 (16.5–19.75) ± 0.56	30.75 (27.75–37.25) ± 1.69	18.45 (16.25–20.25) ± 0.75	12.0 (7,75–15.25) ± 1.40	4.30 (3.75–5.25) ± 0.3	195.0 (175.2–211.2) ± 6.19	30.85 (29.25–33.75) ± 0.79
Peganum harmala	Ad	90.75 (62.75–103.25) ± 7.41	29.35 (27.25–32.25) ± 0.87	23.95 (22.25–26.25) ± 0.70	11.35 (10.50–12.25) ± 0.34	25.10 (23.0–28.75) ± 0.99	23.75 (21.25–26.25) ± 0.85	23.55 (21.75–26.25) ± 0.84	23.45 (18.75–29.75) ± 1.9	15.35 (12.75–17.75) ± 0.94	10.4 (7.75–13.75) ± 1.1	Absent	Absent
	Ab	99.45 (95.25–103.7) ± 1.4	27.60 (22.25–37.75) ± 2.7	25.90 (22.75–29.75) ± 1.2	10.55 (8.75–12.75) ± 0.68	29.55 (27.75–31.25) ± 0.60	24.75 (22.25–27.25) ± 0.97	25.80 (22.25–30.25) ± 1.39	25.45 (18.75–29.75) ± 1.86	15.75 (12.75–17.25) ± 0.83	9.55 (7.75–12.25) ± 0.93	Absent	Absent
Physalis angulata	Ad	59.53 (52.0–75.50) ± 4.53	26.40 (25.25–27.25) ± 0.33	26.05 (25.25–27.25) ± 0.34	9.55 (8.25–10.75) ± 0.46	26.05 (25.25–27.25) ± 0.33	24.05 (22.75–25.75) ± 0.62	59.75 (51.50–76.0) ± 4.52	27.30 (25.75–30.25) ± 0.89	13.15 (12.75–13.75) ± 0.16	6.95 (5.25–8.25) ± 0.53	Absent	Absent
	Ab	43.90 (26.75–51.50) ± 4.81	26.0 (24.75–27.25) ± 0.44	25.45 (24.75–26.25) ± 0.24	3.75 (3.00–4.75) ± 0.28	25.70 (25.25–26.25) ± 0.16	26.0 (25.25–26.75) ± 0.27	37.45 (26.50–52.25) ± 4.97	24.85 (22.75–26.50) ± 0.70	23.0 (21.25–25.75) ± 0.80	7.15 (5.25–9.75) ± 0.93	Absent	Absent

Continued

Table 4. Continued.

Plant name	Ad × Ab	Length of epidermal cell Mean (Min–Max) ± SE (µm)	Width of epidermal cell Mean (Min–Max) ± SE (µm)	Length of guard cells Mean (Min–Max) ± SE (µm)	Width of guard cells Mean (Min–Max) ± SE (µm)	Length of stomata Mean (Min–Max) ± SE (µm)	Width of stomata Mean (Min–Max) ± SE (µm)	Length of subsidiary cell Mean (Min–Max) ± SE (µm)	Width of subsidiary cell Mean (Min-Max) ± SE(µm)	Length of stomatal pore Mean (Min–Max) ± SE (µm)	Width of stomatal pore Mean (Min–Max) ± SE (µm)	Trichome length Mean (Min–Max) ± SE (µm)	Trichome width Mean (Min–Max) ± SE (µm)
Ranunculus sceleratus	Ad	54.15 (47.75–61.25) ± 2.34	41.0 (33.75–47.25) ± 2.53	34.25 (32.75–36.25 ± 0.65	9.85 (8.75–11.25) ± 0.40	34.05 (32.75–35.25) ± 0.43	24.85 (23.0–26.75) ± 0.71	50.20 (42.75–54.50) ±2.1	32.40 (25.25–38.75) ± 2.40	21.30 (20.25–22.25) ± 0.3	7.50 (6.25–8.75) ± 0.41	Absent	Absent
	Ab	64.05 (60.25–67.25) ± 1.21	52.25 (50.25–54.75) ± 0.85	32.15 (28.75–34.75) ± 1.04	10.70 (8.50–12.75) ± 0.88	31.50 (27.75–34.75) ± 1.89	27.45 (25.25–29.75) ± 0.81	53.40 (47.75–59.0) ±1.89	35.85 (27.75–42.75) ± 3.07	20.25 (18.75–21.25) ± 0.47	7.50 (5.25–9.76) ±0.83	Absent	Absent
Ricinus communis	Ad	40.50 (38.75–42.25) ± 0.60	17.0 (13.75–20.25) ± 1.05	33.75 (31.25–38.75) ± 1.31	19.05 (17.25–21.0) ± 0.71	32.85 (31.25–34.25) ± 0.53	18.75 (16.25–21.0) ± 0.89	19.85 (16.25–23.75) ±1.2	9.5 (8.0–12.25) ± 0.74	20.70 (18.75–23.0) ± 0.71	8.15 (6.75–10.25) ± 0.62	Absent	Absent
	Ab	35.15 (32.75–37.75) ± 0.88	18.05 (13.75–24.75) ± 1.83	27.40 (25.50–28.75) ± 0.65	7.55 (6.25–8.75) ± 0.46	26.6 (24.75–28.75) ± 0.75	15.05 (12.75–17.25) ± 0.81	29.15 (26.25–30.75) ± 0.79	11.85 (10.25–13.75) ± 0.69	13.65 (11.25–15.25) ± 0.69	6.60 (5.75–7.75) ± 0.38	Absent	Absent
Sambucus nigra	Ad	61.75 (58.75–63.75) ± 0.85	45.05 (38.75–49.75) ± 1.92	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	Ab	63.75 (61.25–65.25) ± 0.68	35.65 (32.75–38.75) ± 1.10	42.95 (41.25–44.75) ± 0.60	11.45 (10.25–12.75) ± 0.46	46.95 (43.75–49.75) ± 1.15	34.55 (32.75–36.25) ± 0,64	49.55 (47.75–51.25) ± 0.60	23.75 (22.75–24.75) ± 0.35	26.65 (25.25–27.75) ± 0.43	13.75 (12.25–14.75) ± 0.41	118.25 (113.7–123.7) ± 1.9	24.85 (23.75–26.25) ± 0.43u
Solanum nigrum	Ad	69.55 (67.75-71.25) ± 0.64	30.15 (28.75–31.25) ± 0.43	29.80 (28.75–31.25) ± 0.45	7.90 (6.25–9.50) ± 0.56	29.80 (28.75–31.25) ± 0.45	19.10 (17.75–20.25) ± 0.43	29.75 (28.75–31.25) ± 0.47	24.50 (23.75–25.25) ± 0.27	17.25 (16.25–18.25) ± 0.35	1.85 (1.25–2.75) ± 0.29	255.5 (226.2–288.7) ± 11.7	33.45 (31.25–35.25) ± 0.75
	Ab	67.75 (64.75–71.75) ± 1.55	37.15 (35.75–38.75) ± 0.53	27.35 (26.25–28.75) ± 0.43	7.30 (6.25–8.75) ± 0.45	27.35 (26.25–28.75) ± 0.43	16.85 (16.25–17.75) ± 0.29	40.35 (38.75–42.75) ± 0.76	13.0 (11.50–14.75) ± 0.57	17.75 (16.25–19.75) ± 0.61	2.25 (1.25–2.75) ± 0.27	229.1 (138.7–275.2) ± 24.0	39.85 (33.75–48.75) ± 2.47
Solanum incanum	Ad	66.75 (65.25–68.75) ± 0.65	12.25 (11.25–13.25) ± 0.35	21.65 (20.25–22.75) ± 0.43	8.0 (7.25–9.0) ± 0.37	21.55 (20.25–22.75) ± 0.43	14.25 (12.75–15.25) ± 0.44	28.15 (26.25–29.75) ± 0.62	14.45 (13.25–15.25) ± 0.40	14.05 (12.75–15.25) ± 0.43	7.05)6.25–7.75) ± 0.25	218.2 (210.25–225.25) ± 2.85	17.1 (15.25–18.75) ± 0.64
	Ab	34.45 (32.75–36.25) ± 0.60	14.15 (12.75–15.25) ± 0.43	14.15 (12.75–15.25) ± 0.43	6.15 (5.25–7.25) ± 0.40	14.15 (12.75–15.25) ± 0.43	11.35 (10.25–12.75) ± 0.43	27.95 (26.25–29.75) ± 0.60	14.10 (12.75–15.25) ± 0.43	6.65 (5.25–7.75) ± 0.43	5.25 (4.25–6.25) ± 0.35	236.0 (224.75–247.75) ± 3.7	22.85 (21.25–25.25) ± 0.73
Sorghum halepense	Ad	85.20 (64.75–100.2) ± 6.8	21.30 (18.75–24.75) ± 1.03	32.05 (29.75–34.75) ± 0.81	10.30 (8.75–11.75) ± 0.55	31.90 (30.25–33.0) ± 0.50	19.45 (17.75–20.75) ± 0.53	61.9 (52.75–67.75) ± 2.46	22.80 (2125–25.25) ± 0.69	13.85 (12.75–15.25) ± 0.50	3.40 (2.75–4.25) ± 0.26	Absent	Absent
	Ab	47.95 (46.25–49.75) ± 0.60	34.15 (32.75–35.25) ± 0.43	32.95 (31.25–34.75) ± 0.60	10.40 (8.0–12.25) ± 0.85	32.75 (31.25–34.75) ± 0.65	23.05 (21.75–24.75) ± 0.53	44.40 (42.75–46.25) ± 0.61	24.85 (23.75–26.50) ± 0.49	22.20 (21.25–23.0) ± 0.32	4.50 (3.75–5.25) ± 0.25	Absent	Absent
Thevetia peruviana	Ad	35.65 (33.75–37.75) ± 0.67	28.25 (25.25–31.25) ± 1.10									Absent	Absent
	Ab	45.70 (41.25–52.25) ± 2.1	29.10 (26.25–22.75) ± 1.3	25.85 (23.75–27.75) ± 0.79	4.85 (3.75–6.25) ± 0.43	25.60 (23.75–27.75) ± 0.69	15.45 (13.75–17.25) ± 0.60	43.0 (38.75–48.75) ± 1.64	22.50 (18.75–28.75) ± 1.79	12.85 (11.25–14.75) ± 0.64	7.70 (5.50–10.25) ± 0.85	Absent	Absent
Trifolium repens	Ad	30.35 (24.75–36.25) ± 1.90	21.25 (18.75–23.75) ± 0.92	17.95 (16.25–19.75) ± 0.60	5.20 (4.50–6.25) ± 0.30	17.95 (16.25–19.75) ± 0.60	12.30 (11.25–13.25) ± 0.33	34.70 (33.75–35.50) ± 0.32	17.15 (15.25–18.75) ± 0.62	9.85 (8.75–11.25) ± 0.43	3.60 (3.0–4.25) ± 0.21	Absent	Absent
	Ab	42.35 (41.25–43.75) ± 0.43	30.15 (28.75–31.25) ± 0.43	20.25 (17.75–23.75) ± 1.04	7.20 (6.25–8.0) ± 0.32	21.85 (17.75–24.75) ± 1.20	14.55 (13.75–15.25) ± 0.25	44.95 (43.75–46.25) ± 0.40	27.20 (25.75–29.0) ± 0.57	10.50 (8.75–12.25) ± 0.60	4.85 (3.75–6.25) ± 0.43	Absent	Absent

SE, standard error.

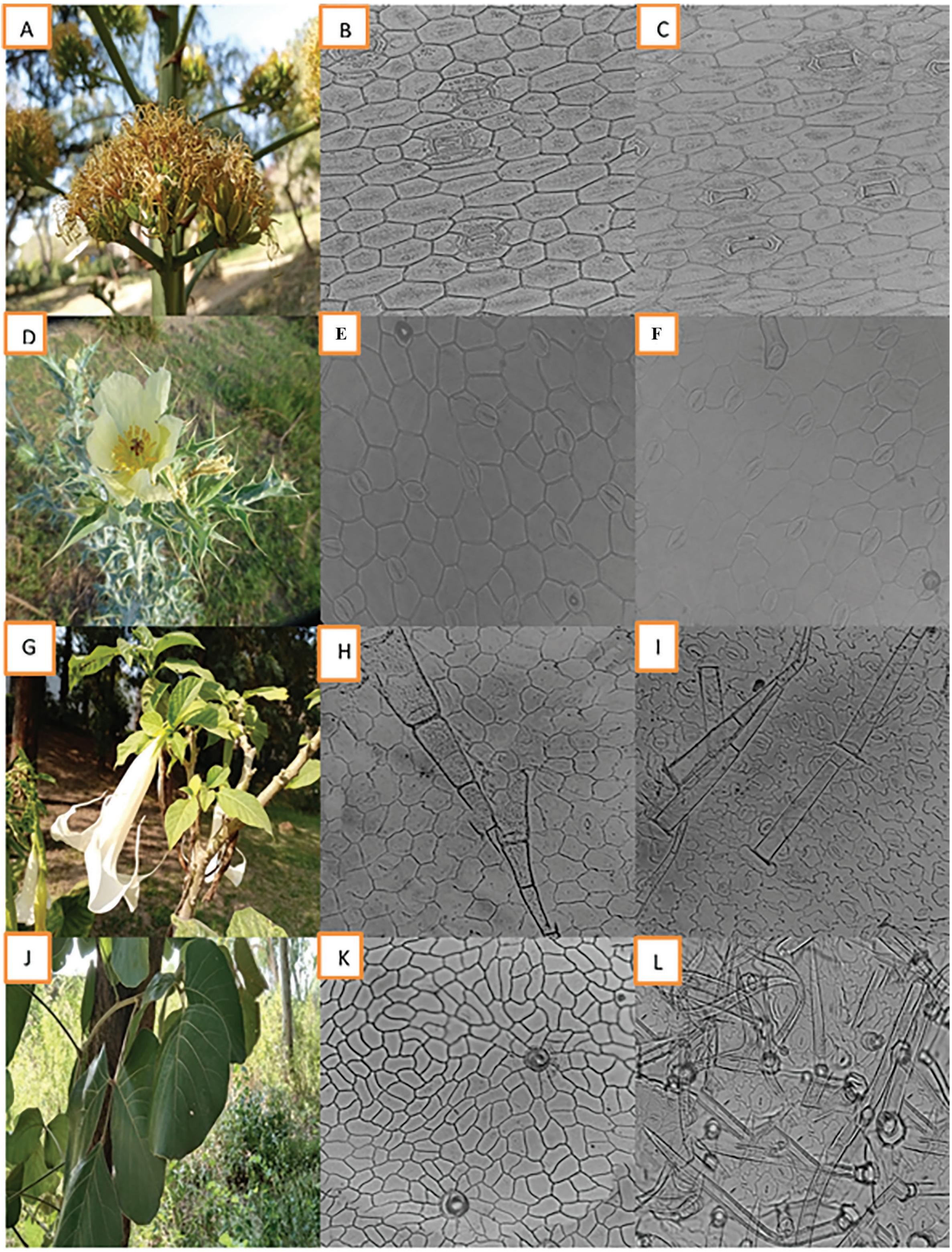

Figure 1. LM shapes of epidermal cells, patterns of AW, stomata and trichomes of poisonous plants. Scale bar = 5 µm. (A) *Agave americana*, (B) adaxial surface, (C) abaxial surface, (D) *Argemone mexicana*, (E) adaxial surface, (F) abaxial surface, (G) *Brugmansia versicolor*, (H) adaxial surface, (I) abaxial surface, (J) *Butea monosperma*, (K) adaxial surface (L) abaxial surface. AW, anticlinal walls; LMs, light micrographs.

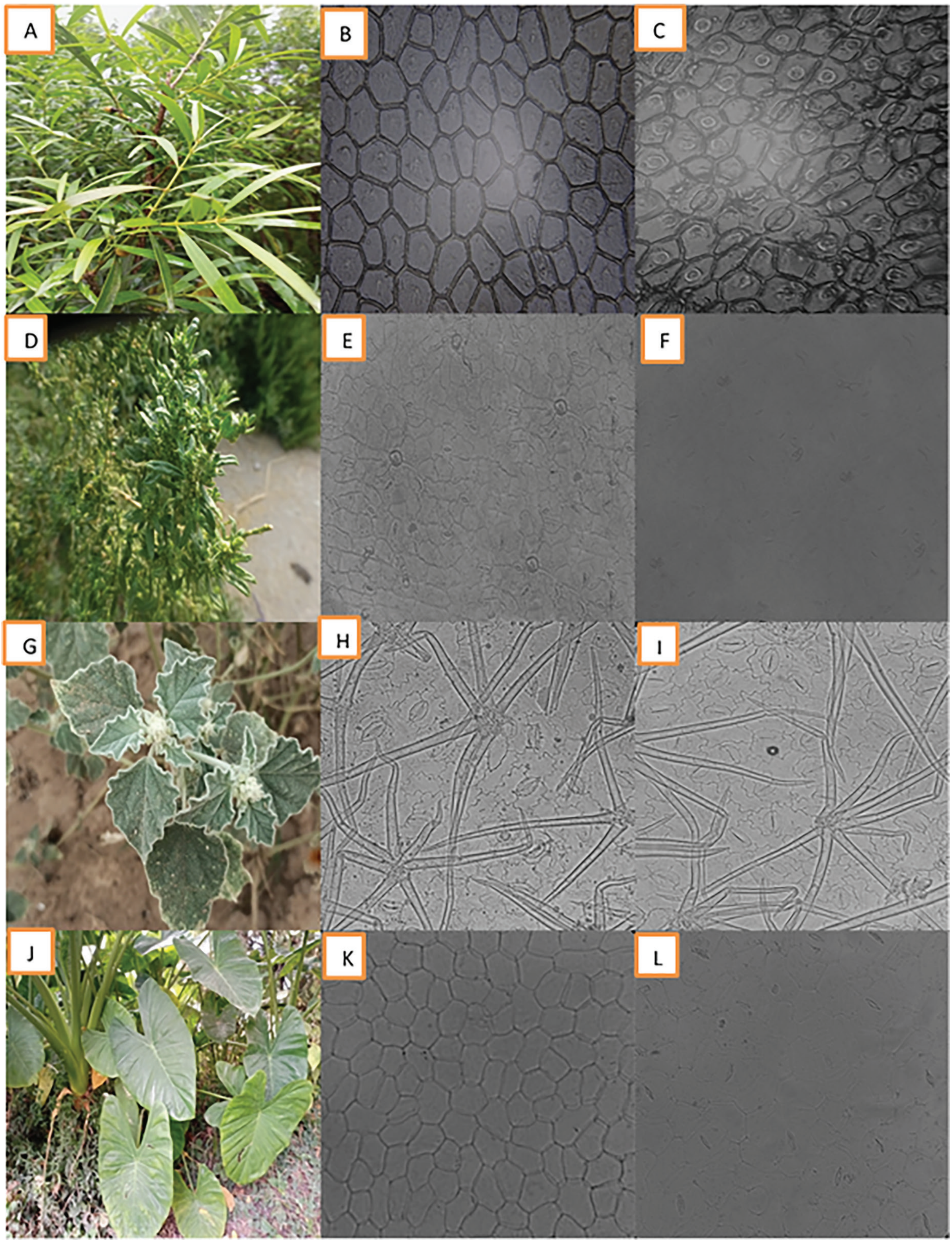

Figure 2. LM shapes of epidermal cells, patterns of AW, stomata and trichomes of poisonous plants. Scale bar = 5 μm. (A) *Buxus pilosula*, (B) adaxial surface, (C) abaxial surface, (D) *Chenopodium ambrosioides*, (E) adaxial surface, (F) abaxial surface, (G) *Chrozophora tinctoria*, (H) adaxial surface, (I) abaxial surface, (J) *Alocasia macrorrhizos*, (K) adaxial surface, (L) abaxial surface. AW, anticlinal walls; LMs, light micrographs.

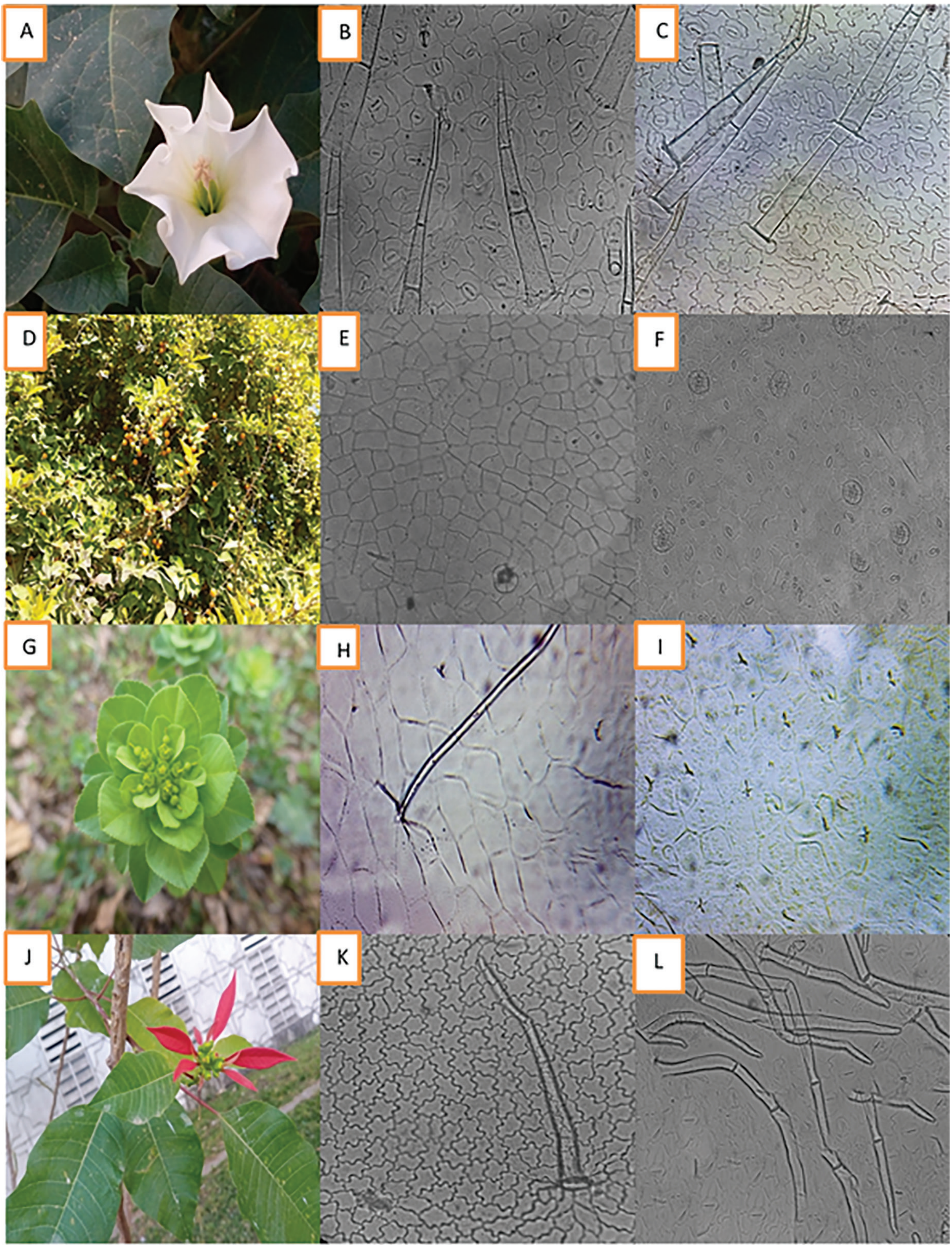

Figure 3. LM shapes of epidermal cells, patterns of AW, stomata and trichomes of poisonous plants. Scale bar = 5 µm. (A) *Datura innoxia*, (B) adaxial surface, (C) abaxial surface, (D) *Duranta repens*, (E) adaxial surface, (F) abaxial surface, (G) *Euphorbia helioscopia*, (H) adaxial surface, (I) abaxial surface, (J) *Euphorbia pulcherrima*, (K) adaxial surface, (L) abaxial surface. AW, anticlinal walls; LMs, light micrographs.

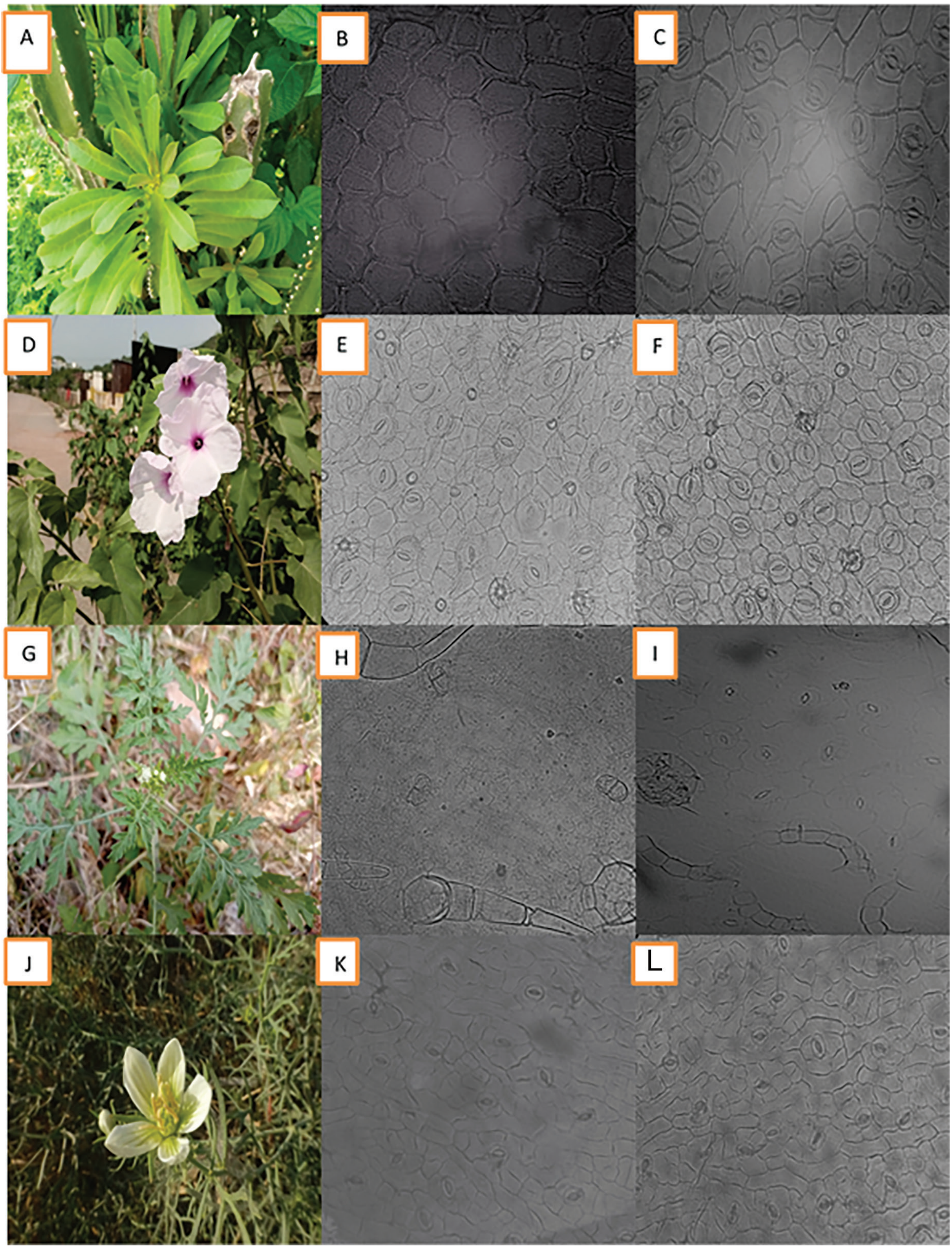

Figure 4. LM shapes of epidermal cells, patterns of AW, stomata and trichomes of poisonous plants. Scale bar = 5 µm. (A) *Euphorbia royleana*, (B) adaxial surface, (C) abaxial surface, (D) *Ipomoea carnea*, (E) adaxial surface, (F) abaxial surface, (G) *Parthenium hysterophorus*, (H) adaxial surface, (I) abaxial surface, (J) *Peganum harmala*, (K) adaxial surface, (L) abaxial surface. AW, anticlinal walls; LMs, light micrographs.

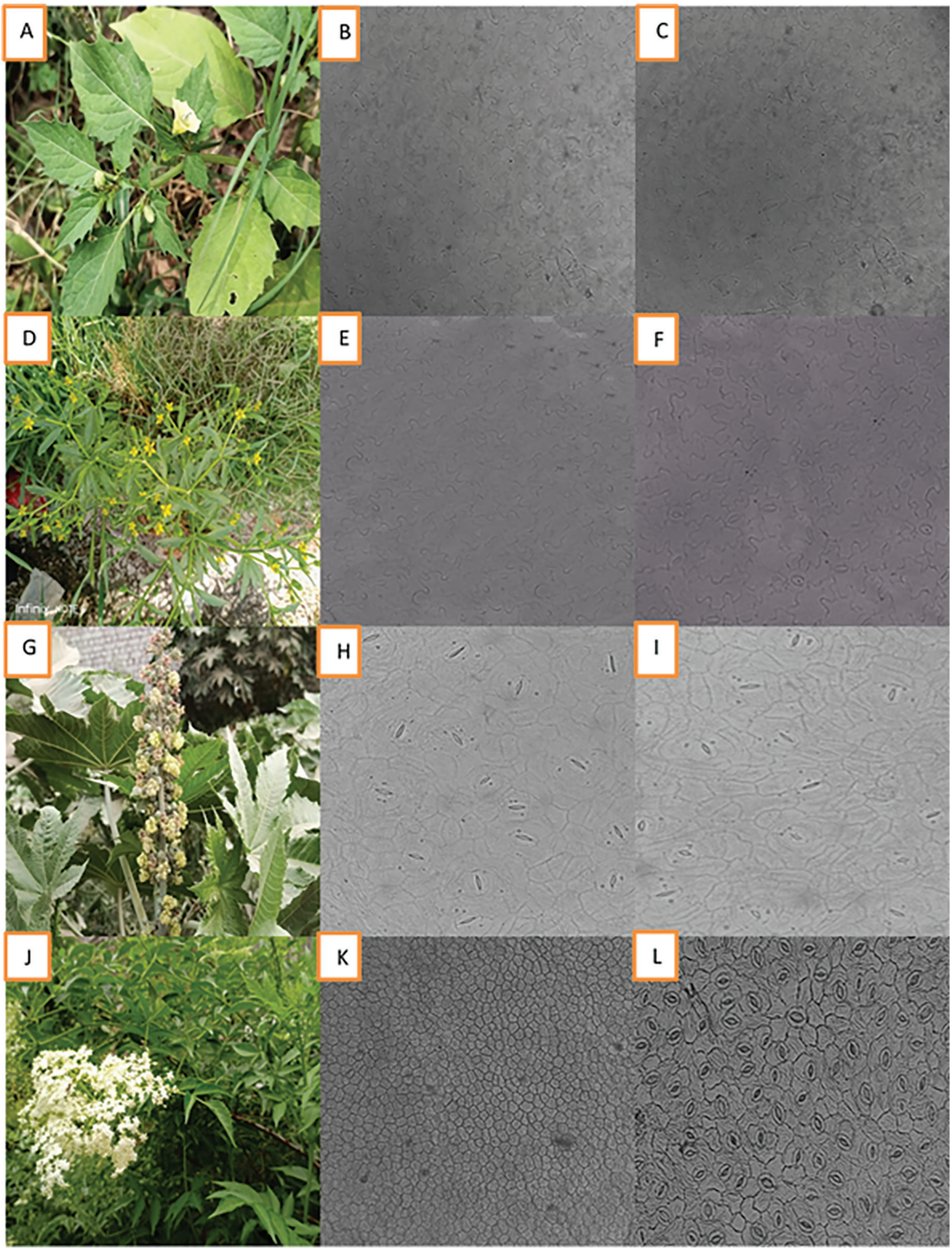

Figure 5. LM shapes of epidermal cells, patterns of AW, stomata and trichomes of poisonous plants. Scale bar = 5 µm. (A) *Physalis angulate*, (B) adaxial surface, (C) abaxial surface, (D) *Ranunculus sceleratus*, (E) adaxial surface, (F) abaxial surface, (G) *Ricinus communis,* (H) adaxial surface, (I) abaxial surface, (J) *Sambucus nigra*, (K) adaxial surface, (L) Abaxial surface. AW, anticlinal walls; LMs, light micrographs.

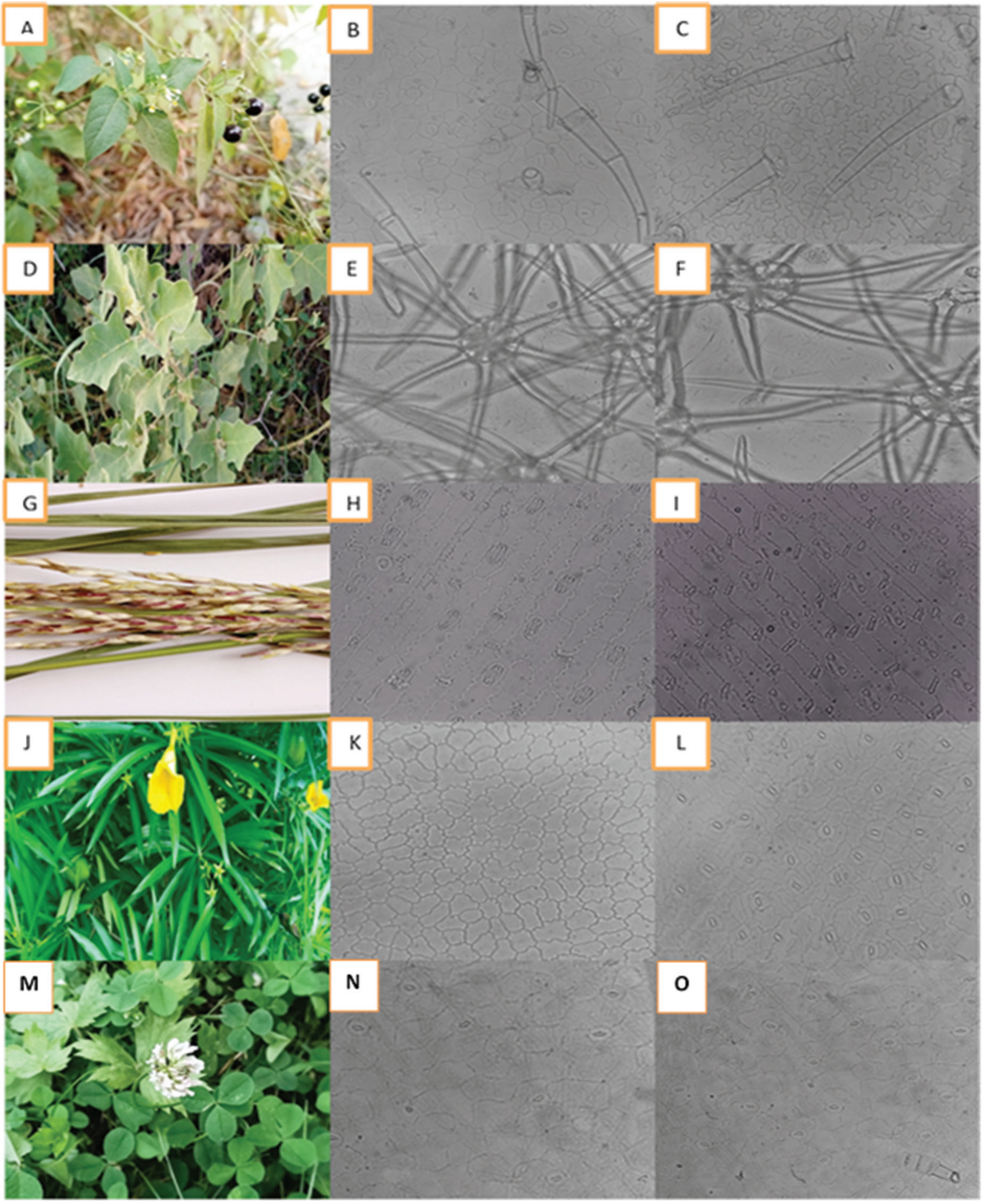

Figure 6. LM shapes of epidermal cells, patterns of AW, stomata and trichomes of poisonous plants. Scale bar = 5 µm. (A) *Solanum nigrum*, (B) adaxial surface, (C) abaxial surface, (D) *Solanum incanum*, (E) adaxial surface, (F) abaxial surface, (G) *Sorghum halepense*, (H) adaxial surface, (I) abaxial surface, (J) *Thevetia peruviana*, (K) adaxial surface, (L) abaxial surface, (M) *Trifolium repens*, (N) adaxial surface, (O) abaxial surface. AW, anticlinal walls; LMs, light micrographs.

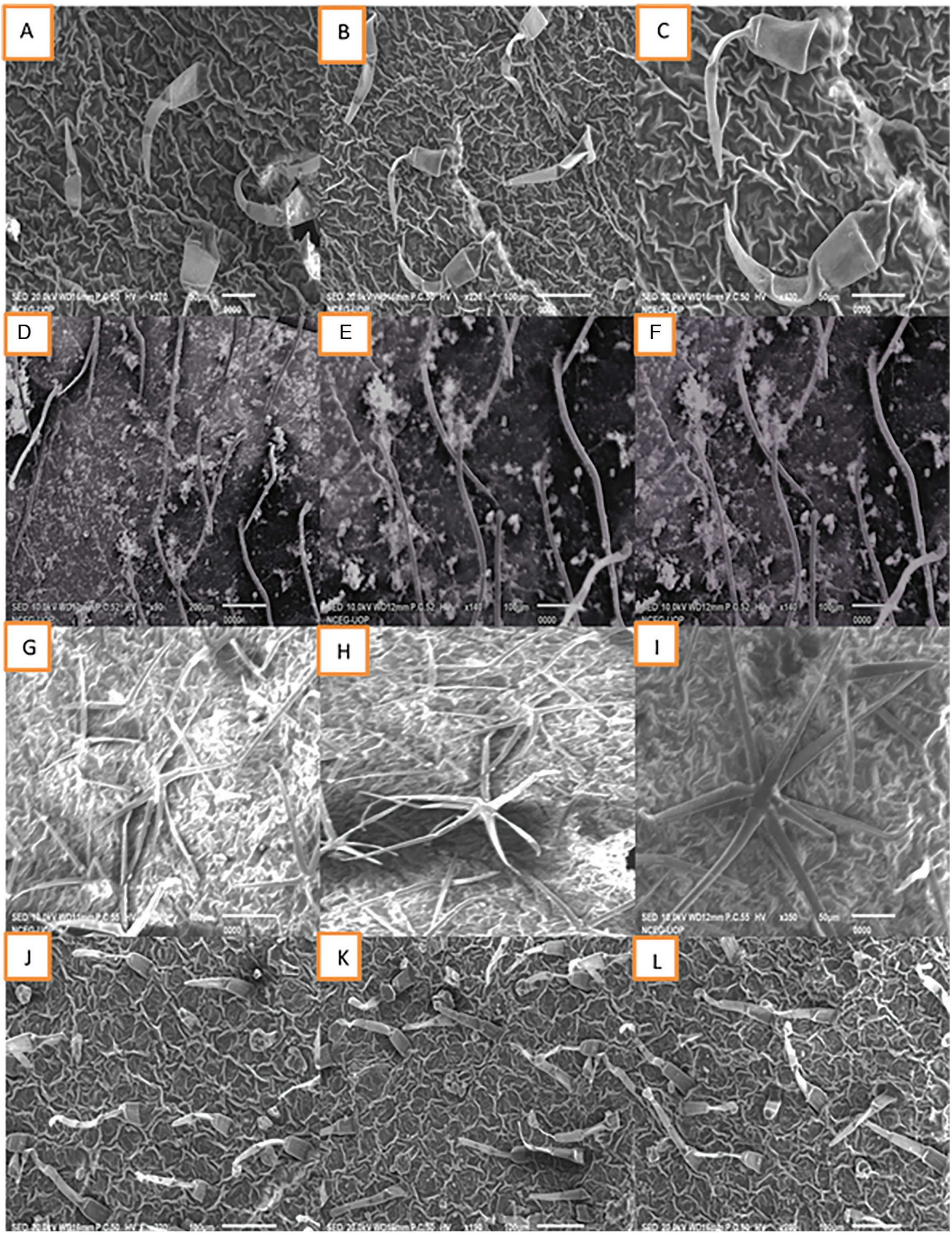

Figure 7. Scanning micrographs (SEM); *Brugmansia versicolor* (A-C), *Butea monosperma* (D-F), *Chrozophora tinctoria* (G-I), *Buxus pilosula* (J-L).

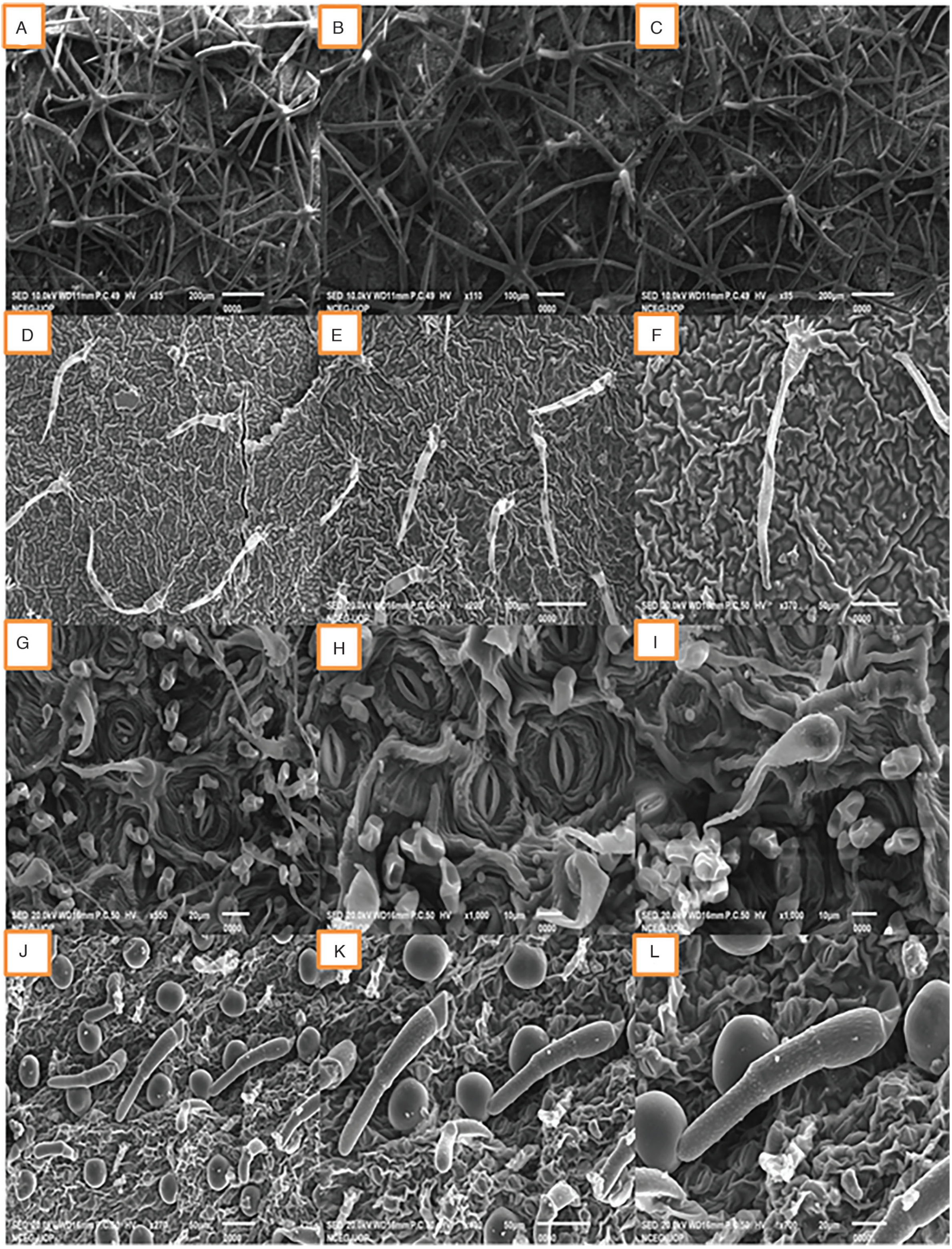

Figure 8. Scanning micrographs (SEM); *Datura innoxia* (A-C), *Duranta rapens* (D-F), *Euphorbia pulcherrima* (G-I), *Euphorbia royleana* (J-L).

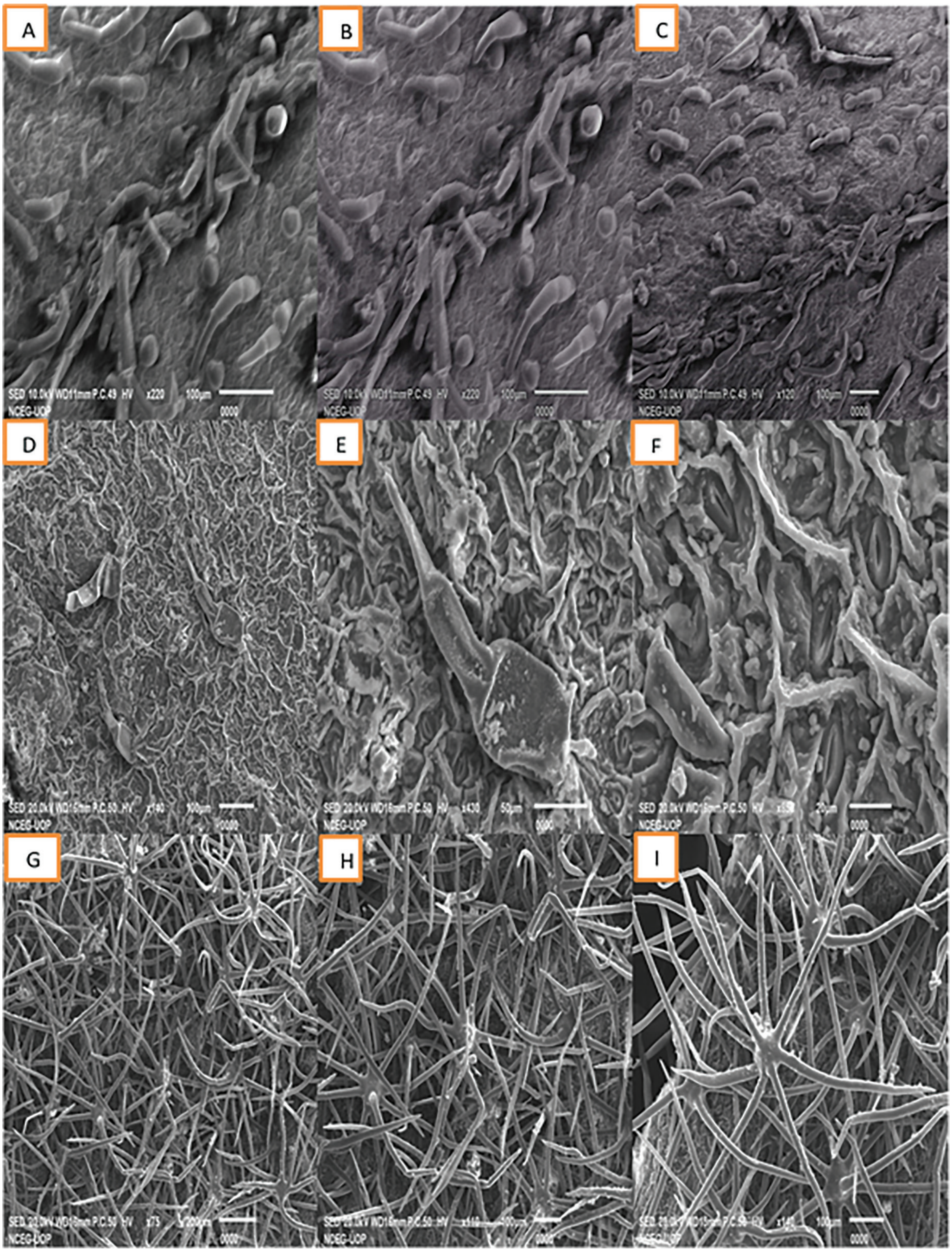

Figure 9. Scanning micrographs (SEM); *Ipomoea carnea* (A-C), *Parthenium hysterophorus* (D-F), *Sambucus nigraum* (G-I).

and the lowest in *E. helioscopia* (2.75 ± 0.14 µm). On the upper side, the highest length of guard cell was detected in *A. macrorrhizos* (34.60 ± 0.64 µm) and *B. monosperma* (14.15 ± 0.36 µm). On the other hand, the highest width of guard cell was found in *E. Helioscopia* (19.50 ± 0.50 µm) and the lowest in *T. repens* (5.20 ± 0.30 µm). On the lower surface, the extreme length of guard cells was examined in *S. Nigra* (42.95 ± 0.60 µm), while the lowest length of guard cells was observed in *B. monosperma* (14.15 ± 0.36 µm), *I. carnea* (14.15 ± 0.36 µm) and *S. incanum* (14.15 ± 0.43 µm). Similarly, the highest width of guard cell was observed in

E. helioscopia (20.25 ± 0.61 µm), while the lowest was found in *T. repens* (3.75 ± 0.28 µm).

Trichomes also vary in length and width. On the adaxial side, the highest length of trichome was found in *E. helioscopia* (895.2 ± 70 µm) and *I. carnea* (39.55 ± 0.60 µm). On the other hand, the highest width of trichomes was observed in *B. versicolor* (46.40 ± 1.93 µm), while *C. tinctoria* (10.45 ± 1.05 µm) was found to have the lowest width of trichomes. On an abaxial surface, the maximum length of trichomes was found in *Brugmansia versicolor* (307.35 ± 2.62 µm), while the minimum was identified in *Chenopodium ambrosioides* (57.70 ± 2.28 µm). The highest width of trichomes was observed in *S. nigrum* (39.85 ±2.47 µm), while the lowest was found in *C. tinctoria* (9.95 ± 0.40 µm).

Qualitative attributes

The qualitative attributes of foliar epidermal anatomy showed significant variations among the studied plant species. Epidermal cells exhibited different shapes, including irregular, isodiametric polygonal, curvy and rectangular. Rectangular-shaped epidermal cells were present on both surfaces of *S. halepense* and on the adaxial surface of *S. incanum*. The pattern of AW also varied, ranging from deeply sinuous, wavy to sinuous, undulate, straight and angular. Thick sinuous walls were observed only in *S. halepense.* Stomata, which are crucial for gas exchange in plants, were observed on both surfaces of the leaves. The upper surface generally had a higher number of stomata than the lower surface. Different types of stomata were identified in the present study, including anisocytic, anomocytic, paracytic and cyclocytic. Cyclocytic stomata were found only in *I. carnea*. Anisocytic stomata have been observed in members of the Solanaceae family. Some species exhibited elliptical and wide elliptical stomatal pores. Dumbbell-shaped guard cells were observed only in *S. halepense.* Trichomes, or plant hairs, are another important aspect of leaf anatomy that can vary significantly among different plant species. Various types of trichomes were observed, including glandular trichomes and non-glandular trichomes. Glandular trichomes were found in Datura, which secrete toxic substances. Non-glandular trichomes, which do not produce any secretions, were observed in plants such as *R. communis* and *S. nigrum*. The density of trichomes also varied, with some plants having a sparse distribution, while others had a dense coverage of trichomes on leaf surfaces. For example, *Datura innoxia* exhibited a high density of glandular trichomes, giving the leaves a rough texture, while *S. nigrum* had a lower density of non-glandular trichomes, and thus a smoother leaf surface. The identified anatomical characteristics play a significant role in distinguishing and identifying poisonous species. The consistent presence or absence of specific characteristics in our study can serve as valuable diagnostic traits for species identification. For example, in our study, we consistently observed irregular epidermal cells with undulate AW, anomocytic stomata and glandular multicellular trichomes in the species of Solanaceae. This combination of features may serve as a distinguishing characteristic for species within this family. By highlighting these consistent features, we provide taxonomists with specific anatomical traits that can be used as diagnostic tools. These traits can be incorporated into identification keys or guides, enabling accurate species identification based on the microscopic examination of leaf epidermal characteristics.

The present study aimed to explore and compare the foliar anatomy of selected species, shedding light on the structural variations and adaptations present in their leaves. Based on the examination of the abaxial side, irregular epidermal cells with undulate AW and anomocytic stomata were observed in Solanaceae species, which is consistent with the findings of Adedeji et al. (2007). Ibrahim et al. (2016) reported rectangular-shaped epidermal cells with undulate cell walls in *D. innoxia* on both surfaces, whereas the present study revealed irregular and polygonal-shaped epidermal cells. The presence of anomocytic and anisocytic stomata was consistent with the findings of Ibrahim et al. (2016), and multicellular non-glandular trichomes were also observed. In *S. nigrum*, polygonal epidermal cells with a wavy pattern of AW on the upper surface and irregular cells with sinuous patterns on the lower surface were observed, which aligns with the findings of previous studies except for the undulate AW on the lower surface. The presence of anisocytic and anomocytic stomata, along with multicellular non-glandular trichomes, was consistent with the findings of previous research. Zahra et al. (2014) studied various Euphorbiaceous species and observed irregular epidermal cells with undulating walls and anisocytic stomata in *E. pulcherrima*, which is similar to the findings of the present study. Multicellular non-glandular trichomes with bulbous bases were also observed, consistent with the findings of previous work. In *E. royleana*, the observed shape of epidermal cells was polygonal, and paracytic stomata with straight AW were found only on the abaxial side. These results deviate from those of previous studies, which reported different-shaped epidermal cells with diacytic stomata. Najmaddin (2020) reported *E. helioscopia* with tetracytic and anomocytic stomata on the abaxial surface, while the current research identified polygonal and irregular epidermal cells with undulating and entire walls, and retained anomocytic stomata. Tyagi et al. (2013) examined the transverse section of *R. communis*, observing collenchyma, microcrystals, oil glands, parenchyma, palisade layers, prismatic crystals and rosette crystals, but there has been no additional foliar anatomical work on *R. communis.* The present study examined polygonal epidermal cells with straight AW and paracytic stomata on both surfaces.

Ramzan et al. (2019) previously described the anatomical characteristics of *B. monosperma* and found the absence of stomata on the adaxial surface and paracytic stomata on the abaxial surface, which is consistent with the current findings. Glandular, unicellular trichomes with pointed tips were also observed, which were not reported by the earlier work. However, the present research identified irregular and polygonal epidermal cells, which deviates from the previous study. Gostin (2009) observed foliar cross-sections of *T. repens*, noting palisade and parenchyma cells, but unfortunately, there is no epidermal anatomical study found in the literature. The current study revealed irregular and polygonal epidermal cells with anomocytic and anisocytic stomata on both the adaxial and abaxial surfaces, along with glandular multicellular trichomes.

In *Ranunculus sceleratus*, irregular epidermal cells with sinuous AW and anomocytic stomata were observed on both the abaxial and adaxial surfaces, with no trichomes recorded, which is consistent with the results of Salim et al. (2016). Bashir et al. (2020) examined irregular and polygonal epidermal cells with wavy to straight AW and paracytic stomata in *T. peruviana*, while the present study identified anisocytic stomata, which was not reported in the literature. Trichomes were not found in both the current and recent research. Arogundade and Adedeji (2019) recently investigated polygonal epidermal cells with straight walls, while brachyparacytic stomata were observed in *Alocasia macrorrhiza* in previous work, whereas the present study found paracytic stomata. In *S. halepense*, sinuous walls of rectangular epidermal cells with paracytic stomata were noted, which is consistent with the finding of Chaudhari et al. (2014). Only *S. halepense* exhibited dumbbell-shaped guard cells in all the mentioned varieties. The abaxial surface of *Duranta erecta* exhibited polygonal-shaped epidermal cells, which was also observed by Shekhawat and Manokari (2017). Gaafar (2019) observed wavy polygonal and irregular epidermal cells with only anisocytic stomata in *Chenopodium ambrosioides*, while the present results showed anisocytic stomata and a wide elliptical shape of the stomatal pore. Al-Mousawi et al. (2019) inspected thick anticlinal-walled epidermal cells and anisocytic stomata in *A. mexicana*, whereas the present study showed polygonal epidermal cells with thin AW and anomocytic stomata.

This research exhibited irregular or rectangular epidermal cells with slightly sinuous AW, along with cyclocytic stomata, in *I. carnea*. Both glandular capitate and non-glandular unicellular conical-shaped trichomes were also observed. These outcomes are consistent with the previous work of Ashfaq et al. (2019). Koyuncu et al. (2008) recorded polygonal epidermal cells with anisocytic stomata in *P. harmala*, while the present study described anomocytic stomata, showing slight deviations from prior work. Amini et al. (2019) examined the foliar cross-section of *S. nigra* and observed parenchyma cells and vascular bundles. Atkinson and Atkinson (2002) examined the high density of stomata on the abaxial surface and the absence of stomata on the adaxial surface. In contrast, the present study revealed polygonal epidermal cells with angular walls, exhibiting anomocytic stomata and multicellular trichomes, which were not mentioned in the literature.

It is important to explore why there are variations in the anatomical features observed in different studies. Factors such as genetic variability, environmental conditions, geographic location and different plant developmental stages could contribute to the observed differences. By focussing on these anatomical characteristics, our research contributes to the understanding of plant diversity and species identification. The consistent traits can be incorporated into taxonomic keys, guides and databases, enabling accurate and efficient identification of poisonous species. Additional research and comparative studies are needed to validate the diagnostic value of these anatomical characteristics. However, our findings lay the foundation for future investigations and provide a starting point for researchers and taxonomists interested in the identification and classification of poisonous species based on leaf anatomical features.

Overall, understanding the foliar anatomy of poisonous plants provides valuable information for their identification and classification. By recognising specific morphological features, dermal structures, glandular structures, secondary metabolites and leaf colouration, botanists, toxicologists and other experts can effectively distinguish poisonous plants from non-toxic species, contributing to public safety and environmental management.

CONCLUSION

This research article demonstrates the successful identification of poisonous plants through the analysis of foliar micromorphology using LM and SEM techniques. This study highlights the efficacy of these methods in distinguishing toxic plant species based on their unique microscopic features. Furthermore, the identification methodology presented in this article has significant implications for public health and safety. As research progresses, the integration of advanced technologies and increased public awareness will play a vital role in safeguarding individuals from the hazards posed by these plants, ultimately promoting public safety and well-being. In the future, research based on hazardous plant identification using DNA barcoding and phytotoxicity testing, as well as phylogenetic analysis, will be required.

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AUTHOR CONTRIBUTIONS

A.A. – field collection, writing- original draft preparation. M.A. – supervision and reviewing the first draft. M.Z. – supervision. S.Z. – review editing and methodological framework. M.F.R. – methods. A.T.A. – statistics. S.S. – visualization. O.K. – statistical interpretation. T.M. – investigation and conceptualization. A.Y. – formal analysis. O.M. – investigation. K.K. – review editing. A.O.M. – methods and software. K.K. – visualization. S.M. – review editing and language correction.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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