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Micromorphology and distribution of trichome in *Saxifraga* L. species from Western Indian Himalaya and its taxonomic implications

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ABSTRACT: Trichomes are present in all species of *Saxifraga* L. barring few exceptions. In present study trichomes of 27 species, (among which 14 species not studied earlier), occurring in Indian Western Himalaya were examined and their distribution on plant parts was recorded. Eight types of trichomes were recognized. Among the all plant parts, trichomes are present on the pedicel of maximum species (26 species) worked out. Structural diversity and distribution of trichomes in different sections and subsections show a little systematic relevance. However, a species level differentiation is possible in this genus and an artificial key based on structure and distribution of trichomes is proposed for species identification.

KEY WORDS: Artificial keys; *Saxifraga*; Species identification; Trichomes; Trichome distribution; Uttarakhand; Western Himalaya.

INTRODUCTION

Trichomes are fine epidermal outgrowths or appendages on the aerial surface of a plant (Simpson, 2010; Werker, 2000). These epidermal structures may be unicellular or multicellular, branched or unbranched, and are either glandular, consisting of a stalk with a terminal glandular head, or non-glandular, consisting of elongated tapering end. A plethora of diversity exists in trichomes of angiosperm species and bear cosmopolitan characteristics of trichome morphology. Very useful information on structure, function and classification of plant trichomes was provided by Metcalfe and Chalk (1950) and in subsequent time plenty of trichomes morphology has been put forward (Callow, 2000; Payne, 1978; Wagner *et al*. 2004). Since the trichomes are present at the surface of plant organs these epidermal structures are outermost extensions of living cells which interact first with the outer environment around the plant. Many functions of trichomes have been suggested in the scientific literature which includes protection from herbivores, protection from small chewing insects, reduction of transpiratory loss of water, facilitation of gaseous exchange in wet weather, attraction of pollinators etc. (Mellon *et al*., 2012; Oelschlagel *et al*., 2009; Peterson and Vermeer, 1984).

Saxifraga L. *sensu lato*, the type genus of the family Saxifragaceae, is one among the large angiosperm genera with about 440–460 species in the world (Akiyama and Gornall, 2012; Mabberly, 2017; The Plant List 2013). Members of this genus are mainly distributed in temperate and alpine zones of high mountains in Europe, Asia, North and South America with few species occurring as far south as Tierra del Fuego in South America (Zhang, 2013). Though no published report is available for the diversity of *Saxifraga* in the entire Himalaya, collation of available literature (Akiyama and Gornall, 2012; Grierson, 1987; Agnihotri and Husain, 2013; Uniyal, 2016 unpublished) the number of species may be inferred far above 100. The interesting feature of this genus is its small stature, subalpine and alpine habitats and invariable possession of trichomes (baring very few completely glabrous species) in different parts of the body. Trichomes of many species were illustrated by Engler and Irmscher (1916–19) in their classic monograph on *Saxifraga*. Gornall (1986) conducted most exhaustive study of trichomes on leaves and pedicels in 213 species of the genus *Saxifraga* based on herbarium specimens available in BM, K, LTR, RNG and UCB (abbreviations based on Thiers, 2008). He reported mainly six types of trichomes which are i) multiseriate with a multicellular, glandular head; ii) uniseriate with a multicellular, glandular head; iii) sessile multicellular glands; iv) multiseriate eglandular; v) uniseriate eglandular; and vi) unicellular, eglandular trichomes. Since the species of the *Saxifraga* are less reported in the Himalayan region, this exhaustive study did not include many Himalayan species.

About 27 species of the *Saxifraga* genus collected during last two decades from different subalpine and alpine zones of Uttarakhand are available in the herbarium of G.B. Pant University, Pantnagar, India. These include 14 species in which trichomes are still not studied for their structure and distribution on plant parts. In the present study all 27 species were studied for trichome structure and distribution.

MATERIALS AND METHODS

Loose specimens were obtained from G.B. Pant University herbarium and different plant parts to be observed for trichomes were dissected out and submerged in washing powder solution (1 tbsp. washing powder in 250 mL tap water) for 4–10 days for clearing, depending upon different species. All plant parts in multiple samples of each species were observed for presence of trichomes. After clearing, separate plant parts were mounted in glycerin and observed under compound microscope in different magnifications (5x, 10x, 45x). Illustrations were drawn with the help of camera lucida, and measurements were taken by using occulometer and stage micrometer. Trichome types were recognized based on the terminology given by Payne (1978).

RESULTS AND DISCUSSION

a) *Structural diversity of trichomes*

In the present study 8 types of trichomes were identified in the studied species. These are:

i) Glandular uniseriate trichome (GU) which is characterised by an elongate basal stalk made up of one row of cells and a multicellular head (fig. 1, 14A).

ii) Glandular biseriate trichomes (GB) which is characterised by an elongate basal stalk made up of two rows of cells and a multicellular head (fig. 1, 14B).

iii) Glandular intermediate trichome (GI) has an elongate basal stalk which is two-cell thick at base but only one cell thick below multicellular head (fig. 1, 14C).

iv) Glandular multiseriate trichome (GM) is characterised by an elongate basal stalk which is made up of more than two rows of cells and a multicellular head (fig. 1, 14D).

v) Eglandular uniseriate trichome (EU) has an elongate body made up of one row of cells and devoid of glandular head (fig. 1, 14E).

vi) Eglandular biseriate trichome (EB) is characterised by an elongate body composed of two rows of cells and devoid glandular head (fig. 1, 14F).

vii) Eglandular intermediate trichome (EI) has an elongate body which is two-cell thick at base but becomes one cell thick in upper half. The glandular head is absent (Fig. 1, 14G).

viii) Eglandular multiseriate trichome (EM) is characterised by the elongate body which is more than two-cell thick, throughout, except the terminal end (fig. 1, 14H).

b) *Presence of trichomes on different plant parts*

Trichomes were found on stem surface (scattered throughout or restricted to nodes), petioles, abaxial and adaxial surfaces of leaf blade, leaf margins, flower pedicel surface, abaxial surface and margins of sepals. Trichomes present on hypanthium are included under abaxial surface of sepals. Distribution of 8 different types of trichomes on different plant parts is summarized in the table-1. Pedicel in *Saxifraga* species is the organ which invariably contains trichomes in all species except the completely glabrous *Saxifraga* species A. This alpine species forms loose cushions on mossy rock surfaces and have an obscure, solitary, apical lime pit on leaves. Flowers are solitary, terminal, tetramerous, with greenish sepals and petals (fig. 2D). It is closer to Chinese species *Saxifraga nana* Engl. and tentatively placed in section *Porphyrion*. In different species different types of trichomes were recorded on pedicel. Leaf margins and sepal margins are the second most hairy plant parts bearing trichomes in 22 species. Trichomes are present on stem in 21 species, on abaxial surface of sepals in 13 species, on leaf adaxial surface in 10 species, on leaf abaxial surface in 8 species, and on petiole in only 4 species. Trichomes were completely absent on petals of all species studied in present investigation. There is no specific pattern of distribution, of particular type, of trichome on particular part(s); therefore, any type of trichome may be found on part of species.

c) *Systematic significance of trichomes*

Distribution of trichomes in sections (classification following Gornall, 1987) is summarised in table 2 which depicts few important facts. The section *Mesogynae,* represented by only one species (*S. cernua*), is completely different from other sections and subsections in bearing only one type of trichome, i.e. glandular uniseriate which characteristically have a broader basal cell in the stalk. All species of this section studied by Gornall (1986) also contain similar (uniseriate) trichomes. In the recent classification of *Saxifraga* L. (*s.str.*) by Tkach *et al*. (2015) this section is retained as a compact monophyletic group in which species have diversified during last 10 million years (Gao *et al*. 2015) and similarity in trichomes is in agreement of this. In Sect. *Micranthes*, Subsect. *Cuneifoliatae* only one species (*S. pseudopallida*) was studied and it contains only eglandular (intermediate, biseriate and multiseriate) types of trichomes thus disagree with Engler and Irmscher (1916–19) and Gornall (1986) indicating variability. The studied species (*S. pseudopallida*) is now shifted to *Micranthes* Haw. genus [as *M. melanocentra* (Franch.) Losinsk.] which diverged from *Saxifraga* genus about 38 million years ago (Gao *et al*. 2015). While most of the *Saxifraga* species have retained both glandular and eglandular trichomes, this species have only eglandular trichomes.

Except these two above mentioned cases, rest of the sections/subsections contain both glandular and eglandular trichomes. Section *Ciliatae* subsection *Hirculoides* contains quite diversified range of trichomes with all categories of trichomes barring glandular intermediate types. Similarly, section *Porphyrion*

Table 1. Trichome diversity and distribution in ***Saxifraga*** species of the Western Himalaya.

Systematic Position and Species	Trichome Type and Distribution							
		Leaf					Sepal	
	Stem	Petiole	Adaxial Surface	Abaxial Surface	Margin	Pedicel	Abaxial Surface	Margin
Sect. ***Ciliatae***, Subsect. ***Hirculoides***								
S. aristulata Hook.f. *et* Thomson	GB					GB		GB
**S. hirculoides* Decne. (Fig. 1, 13A)	EU	EU	EU	EU	EU	EU		EU
S. hirculus L.	EU, EI	EU, EI				EU, EI		EU, EI
S. lychnitis Hook.f. *et* Thomson	EB, EI, GU, GB			GU, GB	GU, GB	EB, EI, GU, GB	EB, GB	EB, GB
S. moorcroftiana (Ser.)Wall. *ex* Sternb.	GB					GB		GB
**S. palpebrata* Hook.f. *et* Thomson (Fig. 1, 12A-12C)	EB, EI					EM	EB	EB
**S. parnassifolia* D.Don (Fig. 1, 8A-8B)	GM				GM	GM	GM	GM
S. saginoides Hook.f. *et* Thomson	EM				EB, EM	EM		GB
Sect. ***Ciliatae***, Subsect. ***Gemmiparae***								
S. brachypoda D.Don					EM	GM	GB	GB
S. filicaulis Wall. *ex* Ser.	EU, EB, EI, GB				GB	EU, EB, EI, GB	GB	GB
S. hispidula D. Don	EU, EI, GU		EU, EI, EM, GI	EU, EI, EM,	EU, EI, EM,	EU, EI, GB	EM, GB	EM
**S. wallichiana* Sternb. (Fig. 1, 6A-6C)	GB				GB, GM	GB		GB
Sect. ***Ciliatae***, Subsect. ***Rosulares***								
S. jacquemontiana Decne.	GB		GB	GB	GB	GB	GB	GB
**S. microphylla* Royle *ex* Hook.f. *et* Thomson (Fig. 1, 3A-3F)	EI				EB, EI	EU, EI		
**S. stella-aurea* Hook.f. *et* Thomson (Fig. 1, 1A-1D)	GU		EU, EB		EU, EB, GB	GB	GB	
Sect. ***Ciliatae***, Subsect. ***Serpylifoliae***								
**S. minutissima* D.S. Rawat (Fig. 1, 2A-2D)			EB		EB, GB	EB, GB		EB, GB
Sect. ***Ciliatae***, Subsect. ***Flagellares***								
S. brunoniana Wall. *ex* Ser.	GB				GM	GB		
**S. mucronulata* Royle (Fig. 1, 10A-10D)	GB				GB	GB		GB
**S. stenophylla* Royle (Fig. 1, 9A-9F)	EU, EB, EM, GB, GM		EM, GM	EM, GM	EM, GM	EU, EB, GB, GI, GM	GB, GM	GB, GM
Sect. ***Ciliatae***, Subsect. ***Hemisphaericae***								
**Saxifraga* species B (Fig. 1, 7A-7D)					EM	EU, GB		EM
Sect. ***Micranthes***, Subsect. ***Cuneifoliatae***								
S. pseudopallida Engl. & Irmsch.	EB, EI	EB, EM	EB, EM	EB, EM	EB, EM	EB, EI	EB, EI	EB, EI
Sect. ***Porphyrion***, Subsect. ***Kabschia***								
**S. andersonii* Engl. (Fig. 1, 11A-11D)	GB, GI		GB, GM	GB, GM	GB, GM, GI	EU, GU, GB, GM	GB	GB
**Saxifraga* sp.- A	-	-	-	-	-	-	-	-
**S. kumaunensis* Engl. (Fig. 1, 5A-5D)					GB, GM	GB		GM
**S. lilacina* Duthie (Fig. 1, 4A-4C)	GB		GB		GB	GB	GB	GB
S. pulvinaria Harry Sm.					EM	EM		
Sect. ***Mesogyne***								
S. cernua L.	GU	GU	GU	GU	GU	GU	GU	GU

GU=glandular uniseriate, **GB**=glandular biseriate, **GI**=glandular intermediate, **GM**=glandular multiseriate, **EU**=eglandular uniseriate, **EB**=eglandular biseriate, **EI**=eglandular intermediate, **EM**=eglandular multiseriate. Species marked by * were not studied by Gornall (1986).

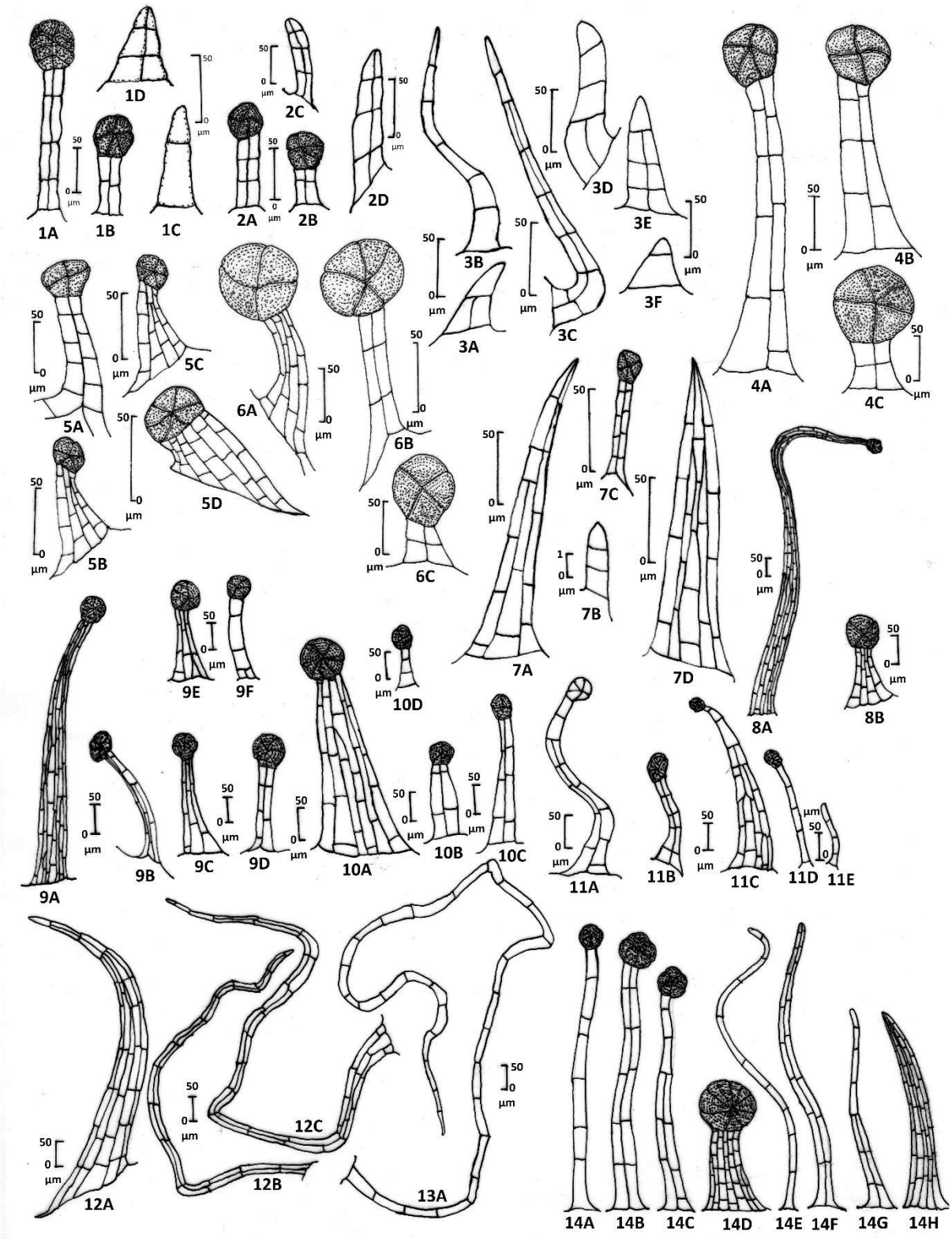

Fig. 1. Trichome structure in West Himalayan ***Saxifraga*** species not studied by Gornall (1986). **1**(A-D): ***S. stella-aurea***; **2**(A-D): ***S. minutissima***; **3**(A-F): ***S. microphylla***; **4**(A-C): ***S. lilacina***; **5**(A-D): ***S. kumaunensis***; **6**(A-C): ***S. wallichiana***; **7**(A-D): ***Saxifraga* species B**; **8**(A-B): ***S. parnassifolia***; **9**(A-F)- ***S. stenophylla***; **10**(A-D): ***S. mucronulata***; **11**(A-E): ***S. andersonii***; **12**(A-C): ***S. palpebrata***; **13**A: ***S. hirculoides***; **14**A: uniseriate glandular trichome (GU); **14**B: biseriate glandular (GB); **14**C: intermediate glandular (GI); **14**D: multiseriate glandular (GM); **14**E: uniseriate non-glandular (EU); **14**F: biseriate non-glandular (EB); **14**G: intermediate non-glandular (EI); **14**H: multiseriate non-glandular (EM)

Fig. 2. Some ***Saxifraga*** species studied for micromorphology and distribution of trichomes in this work. **A**: ***Saxifraga andersonii***, **B**: ***S. brachypoda***, **C**: ***S. brunoniana*** (leaves), **D**: ***Saxifraga*** sp.-**A**, **E**: ***S. moorcroftiana***, **F**: ***S. hispidula***, **G**: ***S. jacquemontiana***, **H**: ***S. lilacina***, **I**: ***S. microphylla***, **J**: ***S. parnassifolia***, **K**: ***S. pseudopallida***, **L**: ***Saxifraga*** species-**B**

Table 2. Trichome distribution in different sections of ***Saxifraga***.

Section/ Subsection	Types of Trichomes							
	GU	GI	GB	GM	EU	EI	EB	EM
Sect. *Ciliatae*, Subsect. *Hirculoides*	+	-	+	+	+	+	+	+
Sect. *Ciliatae*, Subsect. *Gemmiparae*	-	-	+	-	+	+	+	+
Sect. *Ciliatae*, Subsect. *Rosulares*	+	-	+	-	+	+	+	
Sect. *Ciliatae*, Subsect. *Serpylifoliae*	-	-	+	-	-	-	-	+
Sect. *Ciliatae*, Subsect. *Flagellares*	-	+	+	+	+	-	+	+
Sect. *Ciliatae*, Subsect. *Hemisphaericae*	-	-	+	-	+	-	-	+
Sect. *Micranthes*, Subsect. *Cuneifoliatae*	-	-	-	-	-	+	+	+
Sect. *Porphyrion*, Subsect. *Kabschia*	+	+	+	+	+	-	-	+
Sect. *Mesogyne*	+	-	-	-	-	-	-	-

Abbreviations: **GU**=glandular uniseriate, **GB**=glandular biseriate, **GI**=glandular intermediate, **GM**=glandular multiseriate, **EU**=eglandular uniseriate, **EB**=eglandular biseriate, **EI**=eglandular intermediate, **EM**=eglandular multiseriate.

subsection *Kabschia*, section *Ciliatae* subsection *Flagellares* possess six different types of trichomes; subsections *Gemmiparae, Rosulares* of section *Ciliatae* possess five different types of trichomes; and subsections *Cuneifoliatae* of section *Micranthes* and *Hemisphaericae* of section *Ciliatae* contain three types of trichomes. Subsection *Serpylifoliae* of section *Ciliatae* contain one type of glandular and one type of eglandular trichomes. In all, section *Ciliatae*, which is also highly species rich and largest in the Himalaya, contains all eight types of trichomes.

Section *Porphyrion* subsection *Kabschia* which is also accepted as a broadly defined group by Tkach *et al*. (2015) and characterized by thick spathulate leaves with lime secreting hydathodes, glandular hairy flowering stems, and multiseriate glandular and uniseriate eglandular trichomes on pedicel (Gornall 1986, Web & Gornall 1989, Pan *et al*. 2001). In our examination the species belonging to this subsection (*S. andersonii*, S*axifraga* species A, *S. kumaunensis*, *S. lilacina* and *S. pulvinaria*) bear mainly glandular biseriate or multiseriate trichomes on pedicel thus agreeing with the characters of the section. However, *S. pulvinaria* which is mentioned as having glandular trichomes on the pedicel by Akiyama & Gornall (2012) was found having only eglandular multiseriate trichomes in our specimens showing anomaly which may be due to ecological conditions or evolution of different populations.

The studied species here fall in four major groups based on the recent treatment of *Saxifraga* (*s.str*.) genus by Tkach *et al*. (2015). These are genus *Micranthes* Haw., *Saxifraga* sections- *Ciliatae* Haw., *Mesogyne* Sternb. and *Porphyrion* Tausch. These are broadly differentiable based on their trichome structure; *Micranthes* by only eglandular trichomes, *Ciliatae* by wide variety of glandular and eglandular trichomes, *Mesogyne* by only uniseriate glandular trichomes with broader basal cell, and *Porphyrion* by possessing mainly glandular trichomes. However, *Saxifraga* is an extremely large genus with more than 460 species (Akiyama & Gornal 2012) divided in to 13 sections and 19 subsections (Tkach *et al*. 2015); any conclusion on taxonomy of the genus based on a small sample of 27 species (here) is not sufficient.

d) *Common and rare types of trichomes*

Glandular biseriate (GB) trichomes are the most common type and recorded in 18 species while glandular uniseriate (GU) trichomes are least common as recorded in only 4 species (*S. andersonii, S. cernua, S. lychnitis, S. stella-aurea*). Eglandular biseriate (EB) and eglandular uniseriate (EU) trichomes are recorded in 9 species each, englandular multiseriate (EM) in 8, eglandular intermediate (EI) in 7 species, glandular multiseriate (GM) in 6, and glandular uniseriate (GU) in 5 species. Distribution of trichomes on different plant parts indicates presence of all types of trichomes on all investigated plant parts except glandular intermediate (GI) trichomes which were recorded only on stem, adaxial surface of leaves, margin of leaf, and pedicel in few species.

e) *Trichomes in different species*

In present study 27 species were examined for trichome structure and their distribution on different plant parts. Trichomes of 13 species are described below:

i) In *S. aristulata* trichomes were recorded only on stem, pedicel, sepal margin, and are of glandular biseriate type measuring 105–195 µm long with 60–75 ×75 µm large multicellular head. On stem and sepal margin trichomes are sparsely present but on pedicel these are densely present. Gornall (1986) reported only glandular trichomes in this species which are also recorded in our study.

ii) In *S. hirculus* trichomes were recorded on stem, petiole, pedicel and sepal margins. All trichomes are eglandular uniseriate or eglandular intermediate type measuring 1650–2325 µm. In this species our results are similar to Gornall (1986) who also reported only eglandular trichomes in this species.

iii) In *S. lychnitis* glandular and eglandular trichomes are present on stem, abaxial surface and margin of leaves, pedicel, abaxial surface and margin of sepals. Glandular trichomes are either uniseriate or biseriate types measuring 150–450 µm long with 45–60×45–60 µm head, while eglandular trichomes are either uniseriate or intermediate type with a length measuring 150-900 µm. Stem, pedicel and sepals bear glandular

and eglandular trichomes while leaves bear only glandular type of trichomes. Our results are similarto the previous study by Gornall (1986) who also reported both glandular and eglandular trichomes in this species.

iv) *S. moorcroftiana* (fig. 2E) bear only glandular biseriate trichomes which were recorded on stem, pedicel and sepal margins. Trichomes on stem are relatively longer measuring about 495 µm in length with 45–75 µm glandular head. Trichomes on pedicel and sepal margins are smaller than stem trichomes with 180–525 µm length and 60–105×60–135 µm glandular head. Glandular and eglandular both type of trichomes were reported by Gornall (1986) in this species but in our examination we recorded only glandular trichomes.

v) *S. saginoides* bear trichomes on stem, leaf margin (lower half only), pedicel, adaxial surface and margin of sepals. Though both types (glandular and eglandular) of trichomes are recorded in this species, glandular trichomes were represented by glandular biseriate type measuring 120–195 µm length with 45×45 µm head and recorded only on sepal margins. Eglandular trichomes are either biseriate or multiseriate with 1050–1500 µm length. Only glandular trichomes were recorded by Gornall (1986) in this species but in our examination glandular and eglandular both types were found present.

vi) In *S. brachypoda* (fig. 2B) trichomes were recorded on leaf margins, pedicel and sepals. Both glandular and eglandular trichomes were seen but eglandular trichomes represented by multiseriate type were recorded only on leaf margin and are 750–1200 µm long. Glandular trichomes are either biseriate or multiseriate and have 225–750 µm length with 60–75×75–90 µm glandular head. Only glandular trichomes were reported by Gornall (1986) but we also observed some eglandular trichomes in addition to glandular types.

vii) *S. filicaulis* also bear both glandular and eglandular trichomes. These are recorded on stem, leaf margin, pedicel and sepals. Eglandular trichomes were recorded only on stem, pedicel and are of uniseriate, biseriate or intermediate type with a length ranging from 75 µm to 525 µm. Glandular trichomes are represented by only glandular biseriate type and ranges from 150 µm to 550 µm in length with 30–60×45–75 µm head. Both glandular and eglandular trichomes have been reported in this species earlier by Gornall (1986) and our results are in line with the earlier study.

viii) In *S. hispidula* (fig. 2F) total six types of glandular and eglandular trichomes are found on stem, either surfaces and margin of leaves, pedicel, abaxial surface and margin of sepals. Uniseriate or biseriate glandular trichomes measuring 180–675 µm in length with 30–60×45–75 µm head were recorded on stem, adaxial surface of leaves, pedicel and abaxial surface of sepals. Eglandular trichomes of uniseriate, intermediate, multiseriate types were seen on all recorded plant parts and ranges from 75 to 900 µm in length. Gornall (1986) reported glandular and eglandular trichomes in this species which is also found in present study.

ix) *S. jacquemontiana* (fig. 2G) characteristically bear only glandular biseriate trichomes which were recorded on stem, both surfaces and margin of leaves, pedicel, abaxial surface and margin of sepals. These trichomes vary in size from 75–145 µm in length and bear 30–45×45–75 µm large glandular head. Gornall (1986) reported glandular and eglandular both types of trichomes in this species but in our examination only glandular trichomes were recorded on different plant parts.

x) In *S. brunoniana* (fig. 2C) only glandular biseriate and glandular multiseriate trichomes were recorded. Glandular biseriate trichomes were seen on stem, pedicel and ranges from 300–450 µm in length with about 45×60 µm glandular head. Glandular multiseriate trichomes were seen only on leaf margins and measure about 450 µm in length with 45×60 µm glandular head. Our study agrees with Gornall (1986) with record of only glandular trichomes in this species.

xi) Though *S. pseudopallida* (fig. 2K) bear trichomes on all parts, i.e.- stem, petiole, both surfaces and margin of leaves, pedicel, abaxial surface and margin of sepal, these are only eglandular types represented by biseriate, intermediate and multiseriate types. These trichomes vary from 330–900 µm in length. Gornall (1986) has reported only glandular trichomes in this species but differing completely from it we recorded only eglandular types of trichomes on different plant parts.

xii) In *S. pulvinaria* trichomes were recorded only on leaf margin and pedicel. These are eglandular multiseriate type ranging from 75–150 µm in length and sparsely present. Our results are similar to Gornall (1986) who reported only eglandular trichomes in this species.

xiii) *S. cernua* bear trichomes on stem, both surfaces and margin of leaves, pedicel, abaxial surface and margin of sepals. Though, trichomes were recorded on all examined parts, all are glandular uniseriate type and varies from 45–450 µm in length and bear a glandular head measuring 45–75×30 µm. Our results are in complete agreement with Gornall (1986) who reported only glandular uniseriate trichomes in this species.

f) *Trichomes of species not studied earlier*

Fourteen species which were not studied by Gornall (1986) are (marked by '*') listed in the table 1 and their trichomes are depicted in Fig. 1 (1–13). One of the unidentified species (Species A) is completely glabrous. Since the trichomes of these species were not described in earlier works these are briefly described below:

i) In *S. stella-aurea* trichome were recorded on stem, abaxial surface and margin of leaf, pedicel and abaxial

surface of sepal. Rest of the observed parts were found glabrous. The trichomes are glandular biseriate, eglandular biseriate and eglandular uniseriate types. Glandular trichomes ranges from 105–225 µm in length and bear a glandular head measuring 30–60×30–60 µm (Fig. 1, 1A–D).

ii) *S. minutissima* bears trichome on adaxial surface and margins of leaf, pedicel and margin of sepals. Other observed parts are glabrous. Glandular biseriate short trichomes (90–135 µm long with 30–45x30–45 µm head) and eglandular biseriate short trichomes (90–180 µm long) were recorded in this species (Fig. 1, 2A–D).

iii) In *S. microphylla* (fig. 2I) trichomes were recorded on stem, leaf margin and pedicel while other observed parts were glabrous. Only eglandular uniseriate, eglandular biseriate and eglandular intermediate types of trichomes were recorded. These trichomes vary in length from 60–315 µm (Fig. 1, 3A–F).

iv) *S. lilacina* (fig. 2H) bears trichome throughout stem surface, adaxial surface and margin of leaf, pedicel, abaxial surface and margin of sepal. Rest parts are glabrous. This species bears only glandular biseriate trichomes which measure 75–450 µm in length with 15–75×30–90 µm glandular head (Fig. 1, 4a–C).

v) *S. kumaunensis* bears trichome on leaf margin, pedicel and sepal margin. Rest of the examined parts are glabrous. Only short, glandular biseriate or multiseriate trichomes usually in antrorse orientation were recorded. These trichomes ranges from 120–180 µm in length with 15–60×15–60 µm large glandular head (Fig. 1, 5A–D).

vi) In *S. wallichiana* trichomes were recorded on stem, leaf margin, pedicel and sepal margin, while other observed parts were found glabrous. Only glandular trichomes were recorded and represented mainly by glandular biseriate types of trichomes. Glandular multiseriate trichomes were found on leaf margin only. These glandular trichomes ranges from 105–300 µm in length and bear 60–90×75–90 µm large glandular head (Fig. 1, 6A–C).

vii) *Saxifraga* species B (fig. 2L) bears trichomes on leaf margin, pedicel and sepal margin. Rest of the observed parts were glabrous. Trichomes are both glandular and eglandular types and represented by glandular biseriate, eglandular uniseriate and eglandular multiseriate types. Glandular biseriate trichomes are about 105 µm long and bear 30x30 µm large glandular head. Eglandular trichomes vary in length from 75–300 µm. This unidentified species has fimbriate leaves which are characteristically found in the subsect. *Hemisphaericae* based on which it is listed in this subsection (Fig. 1, 7A–C).

viii) *S. parnassifolia* (fig. 2J) bears trichomes on stem, leaf margin, pedicel, abaxial surface and margin of sepal. Other observed parts were glabrous. Trichomes are invariably glandular multiseriate types. These trichomes ragnes from 150–1680 µm in length and bear a glandular head measuring 60–120×45–120 µm. Comparatively longer trichomes were seen at the node (Fig. 1, 8A–B).

ix) *S. stenophylla* bears trichomes on stem, both surfaces and margin of leaf, pedicel, abaxial surface and margin of sepal. Petal, stamen and carpel are glabrous. All eight types of trichomes (glandular uniseriate, biseriate, intermediate, multiseriate; elandular uniseriate, biseriate, intermediate, multiseriate) are recorded only in this species of *Saxifraga*. Glandular trichomes varies in length from 195–675 µm with a glandular head measuring 30–75×45–75 µm. Eglandular trichomes ranges from 90–450 µm in length (Fig. 1, 9A–F).

x) In *S. mucronulata* trichomes were seen on stem, either surface and margin of leaf, pedicel, abaxial surface and margin of sepal. Petal, stamen and carpel are glabrous in the species. The trichomes recorded were mainly glandular biseriate type. However, glandular uniseriate and glandular multiseriate trichomes were also observed rarely. These trichomes vary in length from 90–630 µm in length and the glandular heads vary from 30–75×30–90 µm (Fig. 1, 10A–D).

xi) In *S. andersonii* (fig. 2A) trichomes were recorded throughout the stem surface, surfaces of leaf and leaf margin, pedicel, abaxial surface and margin of sepal. Petal, stamen and carpel are glabrous. The trichomes recorded were mainly glandular and represented by glandular uniseriate, glandular multiseriate, glandular biseriate and glandular intermediate types. These glandular trichomes vary in length from 150–600 µm and bear a glandular head measuring 30–60×30–60 µm. Eglandular uniseriate trichomes were recorded only on pedicel and vary in length from 150–495 µm (Fig. 1, 11A–E).

xii) In *S. palpebrata* trichomes were seen on stem, adaxial surface and margin of leaf, pedicel, abaxial surface and margin of sepal. Trichomes were only eglandular type and represented by eglandular intermediate, biseriate and multiseriate types varying in length from 225–2100 µm (Fig. 1, 12A–C).

xiii) In *S. hirculoides* trichomes were found present throughout the surface of stem, either surface of leaf, leaf margin, petiole, pedicel, abaxial surface and margin of sepal. Petal, stamen and carpel are glabrous. Only long, curly, non-glandular, uniseriate brownish trichomes were recorded which vary in length from 1950–3675 µm (Fig. 1, 13A).

g) *Artificial key based on trichomes*

Distribution of trichomes in *Saxifraga* is mentioned as useful character supporting Englers's classification (Engler and Irmscher, 1916–19) of the genus (Gornall, 1986). Invariable presence of trichomes on different parts and wide diversity of trichome types would be considered as specific character for species identification.

An artificial key based on trichome structure and distribution on plant parts was devised and given ahead:

1a. Plants completely glabrous ..... ***S.* species A**
1b. Plants with trichomes 2
2a. Stem glabrous 3
2b. Stem with trichomes 7
3a. Leaf adaxial surface with trichomes ..... ***S. minutissima***
3b. Leaf adaxial surface glabrous 4
4a. Sepal abaxial surface with trichomes ..... ***S. brachypoda***
4b. Sepal abaxial surface glabrous 5
5a. Sepal margin glabrous ..... ***S. pulvinaria***
5b. Sepal margin with trichomes 6
6a. Leaf margin with eglandular trichomes ..... ***S.* species B**
6b. Leaf margin with glandular trichomes ..... ***S. kumaunensis***
7a. Petiole with trichomes 8
7b. Petiole glabrous 11
8a. Leaf margin in upper half glabrous ..... ***S. hirculus***
8b. Leaf margin with trichomes all along the margin 9
9a. Sepal margin glandular hairy ..... ***S. cernua***
9b. Sepal margin eglandular hairy 10
10a. Sepal abaxial surface glabrous ..... ***S. hirculoides***
10b. Sepal abaxial surface hairy ..... ***S. pseudopallida***
11a. Leaf margins glabrous 12
11b. Leaf margins hairy 14
12a. Trichomes on stem, pedicel and sepal margin eglandular ..... ***S. palpebrata***
12b. Trichomes on stem, pedicel and sepal margin glandular 13
13a. Pedicel trichomes 100–200 µm long ..... ***S. aristulata***
13b. Pedicel trichomes 500–600 µm long ..... ***S. moorcroftiana***
14a. Sepal abaxial surface glabrous 15
14b. Sepal abxial surface with trichomes 19
15a. Sepal margins glabrous 16
15b. Sepal margins with trichomes 17
16a. Pedicel and leaf margin trichomes eglandular ..... ***S. microphylla***
16b. Pedicel and leaf margin trichomes eglandular ..... ***S. brunoniana***
17a. Stem and pedicel trichomes eglandular …..... ***S. saginoides***
17b. Stem and pedicel trichomes glandular 18
18a. Trichomes present throughout the intermodal region ..... ***S. mucronulata***
18b. Trichomes on stem restricted to nodal region …..... ***S. wallichiana***
19a. Leaf abaxial surface with trichomes 20
19b. Leaf abaxial surface glabrous 24
20a. Adaxial surface of leaves glabrous ..... ***S. lychnitis***
20b. Adaxial surface of leaves with trichomes 21
21a. Leaf margins with exclusively glandular biseriate hairs …….. ***S. jacquemontiana***
21b. Leaf margins with eglandular or mixed glandular trichomes 22
22a. Leaf margins with eglandular trichomes only …..... ***S. hispidula***
22b. Leaf margins with glandular or mixed trichomes 23
23a. Leaf margins with glandular trichomes only ..... ***S. andersonii***
23b. Leaf margins with glandular and eglangular trichomes ..... ***S. stenophylla***
24a. Trichomes on pedicel glandular multiseriate ..... ***S. parnassifolia***
24b. Trichomes on pedicel glandular biseriate 25
25a. Leaf adaxial surface glabrous ..... ***S. filicaulis***
25b. Leaf adaxial surface with trichomes 26
26a. Sepal margin with glandular biseriate trichomes ..... ***S. lilacina***
26b. Sepal margins glabrous ..... ***S. stella-aurea***

CONCLUSION

Trichome functions and their diversity are most important in plants. These epidermal structures are present on almost all aerial plant surfaces in *Saxifraga* and their diversity and occurrence are now better known in this genus today after the initial study by Engler and Irmscher (1916–19), exhaustive study of Gornall (1986), and the present work will supplement the former study. In addition, present work also suggests regarding the utility of trichome diversity and distribution for identification of 27 species occurring in Uttarakhand. However, the functions of trichomes present on different plant surfaces in this genus occurring in stressful cold environments of the world are still elusive despite the general assumption that trichomes may be helpful in tolerance to draught, high UV radiations, and low temperature (Benz and Martin, 2006; Jefree, 1986; Skaltsa *et al*., 1994; Agrawal *et al*., 2004).

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