Morphological Classification of Trichomes Associated with Possible Biotic Stress Resistance in the Genus *Capsicum*

Hyun Jung Kim, Eunyoung Seo, Ji Hyun Kim, Heejin Cheong, Byoung-Cheorl Kang and Doil Choi*

Department of Plant Science and Plant Genomics and Breeding Institute, Seoul National University, Seoul 151-921, Korea

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Trichomes are specialized epidermal structure having the functions of physical and chemical block against biotic and abiotic stresses. Several studies on *Capsicum* species revealed that virus and herbivore resistance is associated with trichome-formation. However, there is no research on the structural characterization of trichomes developed on the epidermis of *Capsicum* spp. Thus, this study attempts to characterize the trichome morphologies in 5 species of *Capsicum* using a Field Emission Scanning Electron Microscopy (FESEM). Six main trichome types were identified by their morphology under FESEM. Both glandular and non-glandular types of trichomes were developed on the epidermal tissues of *Capsicum* spp. The glandular trichome were further classified into type I, IV and VII according to their base, stalk length, and stalk. Non-glandular trichomes were also classified into type II, III, and V based on stalk cell number and morphology. Almost all the species in *C. chinense* and *C. pubescens* had glandular trichomes. To our knowledge, this is the first study on classification of trichomes in the genus *Capsicum* and, our results could provide basic informations for understanding the structure and function of trichomes on the epidermal differentiation and association with biotic stress tolerance.

Keywords : *Capsicum*, FESEM, trichome

Trichomes have single or multi-cellular structures that originate from epidermal cells of plant tissues, which can largely be classified into glandular or non-glandular forms (Fahn, 2000, Kolb and Muller, 2004). The organ has generally been regarded as a trait of little worth in agriculture due to its negative aspects such as a causing agent for allergy and a lower preference of farmers. However, the trichomes have demonstrated to be directly or indirectly engaged in the plant protection from ultraviolet radiation, drought, high salinity (Espigares and Peco, 1995; Skaltsa et

al., 1994), heavy metals (Ager et al., 2003), herbivores, and pathogen attacks (Elle et al., 1999; Johnson, 1975; Levin, 1973). Glandular trichomes in Solanaceae species give a high level of resistance against a number of phytophagous arthropods by producing exudate containing toxic acyl-sugars such as at the tips of type VI trichomes of tomato plants (Kennedy, 2003).

Epidermal structures of plants have complex shapes and functions and there are also variations of trichome types in the same plant surface (Glover and Martin, 2000). Trichome has several important microscopic characteristics that can be used for comparative systematics. Variation in trichome types can also provide insight into the evolutionary relationships within and among species (Payne, 1978; Theobald et al., 1979). In many plant groups, trichomes are frequently present, easily observable, and often possess variable patterns. Taxonomic characters of particular types of trichomes have been investigated in many plant species, particularly ferns and flowering plants such as *Arabidopsis* (Valverde et al., 2004), tomato (*Solanum lycopersicum*) (Levin, 1973), potato (*Solanum tuberosum*) (Plaisted et al., 1992), and eggplant (*Solanum melongena*) (Frary, 2003).

Trichomes on a single plant also has several different types on hypocotyls, stems, leaves, floral organs, and immature fruit of cultivated tomato (*Solanum lycopersicum*) (Kang et al., 2010). Luckwill's taxonomic survey of tomato species demonstrated four morphologically distinct glandular trichomes: type I trichomes characterized by a multi-cellular base, a long (~2 mm) multi-cellular stalk, and a small glandular tip; shorter (~0.3 mm) type IV trichomes which have a unicellular base, a multi-cellular stalk shorter than type I, and a small glandular tip; type VI trichomes containing a four-celled glandular head on a short (~0.1 mm) multi-cellular stalk; and type VII trichomes consisting of a short (<0.05 mm) unicellular stalk and an irregularly shaped 4 to 8 cell gland. Type II and type III hairs are similar in length (0.2–1.0 mm), but differ by the presence of a multicellular and unicellular base, respectively, whereas type V trichomes are shorter (0.1–0.3 mm) and have a unicellular base (Luckwill, 1943). There is a considerable diversity of trichome habits, and chemical composition

*Corresponding author.

Phone) +82-2-880-4568, FAX) +82-2-873-2056

E-mail) doil@snu.ac.kr

within the tomato species (Schilmiller et al. 2008, Antonious, 2001).

Chili pepper is one of the most important vegetable crop in the world, and quite a few studies were undertaken in molecular biology, genetics and breeding (Kim et al., 2010; Yoon et al., 2009; Yeom et al., 2011; Oh et al., 2008). Because of the association of trichome-forming phenotype with multiple biotic stress resistances, studies on genetic analysis of trichome-formation in pepper plants were performed (Kim et al., 2010). Association of trichome-forming phenotype with pepper mottle virus (*PepMoV*) resistance was also examined and revealed that the trichome density of the main stem was tightly linked to *PepMoV* resistance in pepper cultivar CM334 (Kim et al., 2011). However,

there had been no report on trichome classification developed on epidermis of the genus *Capsicum*.

In this study, the morphology of trichomes in the stem and leaf surface of 5 *Capsicum* species was observed by Field Emission Scanning Electron Microscopy (FESEM). When compared with the trichomes reported in tomato plants, pepper trichomes were categorized as six distinct types based on the morphology.

Plant materials and growth conditions. Fifty-four accessions of pepper plants (*Capsicum* species) from National Agrobiodiversity Center of RDA in Korea were used for trichome analysis (Table 1). All plants were grown in a walk-in chamber, with a regulated temperature of between

Table 1. *Capsicum* germplasms used in this study

No.	Accession No.	Species (cv)	Name or code No.	Trichome type on stem	Trichome type on leaf
1	06A-121	<i>C. annuum</i> var. <i>annuum</i>	Criollos de morelos 334	V	V
2	06A-134	<i>C. annuum</i> var. <i>annuum</i>	Dempsey	VII	VII
3	06A-139	<i>C. annuum</i> var. <i>annuum</i>	Jamaican Yellow	V, VII	V, VII
4	07A-207	<i>C. annuum</i> var. <i>annuum</i>	CHILI SERRANO	V, VII	VII
5	07A-208	<i>C. annuum</i> var. <i>annuum</i>	CO1436	III, VII	VII
6	07A-217	<i>C. annuum</i> var. <i>annuum</i>	NARC-4	V, VII	V, VII
7	07A-218	<i>C. annuum</i> var. <i>annuum</i>	PBC646/PBC378*5	V, VII	V, VII
8	07A-229	<i>C. annuum</i>	CO 1727	V, VII	V, VII
9	07A-236	<i>C. annuum</i> var. <i>annuum</i>	Carillina cayenne	V, VII	VII
10	07A-267	<i>C. annuum</i> var. <i>annuum</i>	DE ARBOL	II, VII	VII
11	99G-198	<i>C. annuum</i> var. <i>annuum</i>	KC 217 triploid progeny	V, VII	VII
12	99G-204	<i>C. annuum</i> var. <i>annuum</i>	KC 217 triploid progeny	V, VII	VII
13	AC08-028	<i>C. frutescens</i>	C00657	V, VII	VII
14	AC08-028-2	<i>C. frutescens</i>	C00657	V, VII	VII
15	AC08-028-3	<i>C. frutescens</i>	C00657	V, VII	VII
16	AC08-028-4	<i>C. frutescens</i>	C00657	VII	VII
17	AC08-053	<i>C. pubescens</i>	C01324	IV, VII	IV, VII
18	AC08-071	<i>C. baccatum</i>	C04066	V, VII	V, VII
19	AC08-073	<i>C. baccatum</i>	C04068	II, VII	II, VII
20	AC08-105	<i>C. annuum</i> var. <i>annuum</i>	Ypamcho	V, VII	VII
21	AC08-178	<i>C. annuum</i> var. <i>annuum</i>	Red mushroom	V, VII	VII
22	AC08-185	<i>C. annuum</i>	Serrano chili	II, V, VII	V
23	AC08-198	<i>C. annuum</i> var. <i>annuum</i>	Numex St.Patrick's Day	V, VII	VII
24	AC09-055	<i>C. annuum</i> var. <i>annuum</i>	Ikom II	V, VII	VII
25	AC09-059	<i>C. annuum</i> var. <i>annuum</i>	Unknown	V, VII	VII
26	AC09-063	<i>C. annuum</i> var. <i>annuum</i>	Unknown	V, VII	VII
27	AC09-071	<i>C. annuum</i> var. <i>annuum</i>	Unknown	II, V, VII	V, VII
28	AC09-210	<i>C. annuum</i>	Numex Garnet	VII	VII
29	AC09-222	<i>C. annuum</i>	Numex Valentine	V, VII	VII
30	AC09-232	<i>C. annuum</i>	Floral Gem	II, V, VII	VII
31	R09-007	<i>Capsicum</i> sp.	IT 158280	V, VII	VII
32	R09-008	<i>C. annuum</i> var. <i>annuum</i>	SC9	II, V, VII	VII
33	R09-018	<i>C. annuum</i> var. <i>annuum</i>	Tenkostenna Moravska Krajova	II, VII	VII

Table 1. Continued

No.	Accession No.	Species (cv)	Name or code No.	Trichome type on stem	Trichome type on leaf
34	R09-019	<i>Capsicum</i> sp.	VAR.CORNDUTUM F1-50	II, V, VII	VII
35	R09-040	<i>C. annuum</i> var. <i>annuum</i>	K002967	V, VII	VII
36	R09-050	<i>C. annuum</i> var. <i>annuum</i>	PBC413 TAM Mildjalapeno-1	V, VII	VII
37	R09-056	<i>C. annuum</i> var. <i>annuum</i>	Guajillo ancho	V, VII	VII
38	R09-057	<i>C. annuum</i> var. <i>annuum</i>	China	V, VII	VII
39	R09-083	<i>C. annuum</i> var. <i>annuum</i>	IN.JA.VM5	V, VII	VII
40	R09-093	<i>C. annuum</i> var. <i>annuum</i>	97JA VM 4	V, VII	VII
41	R09-114	<i>C. annuum</i> var. <i>annuum</i>	Hot Pepper AL	V, VII	V, VII
42	R09-142	<i>C. annuum</i> var. <i>annuum</i>	Subicho	V, VII	VII
43	R09-162	<i>C. annuum</i> var. <i>annuum</i>	HDA295	V, VII	VII
44	R10- 198	<i>C. annuum</i> var. <i>annuum</i>	K153368	V, VII	V, VII
45	R10-001	<i>C. annuum</i> var. <i>annuum</i>	Gimjanggochu	II, VII	II, VII
46	R10-012	<i>C. annuum</i> var. <i>annuum</i>	Jinan	V	VII
47	R10-021	<i>C. annuum</i> var. <i>annuum</i>	—	II, V, VII	VII
48	R10-027	<i>C. annuum</i> var. <i>annuum</i>	IT105847	V	VII
49	R10-039	<i>C. annuum</i> var. <i>annuum</i>	Samcheok	II, V, VII	V, VII
50	R10-047	<i>C. annuum</i> var. <i>annuum</i>	Serrano Chill	V, VII	VII
51	R10-050	<i>C. annuum</i> var. <i>annuum</i>	Gwangju	II, VII	VII
52	R10-055	<i>C. chinense</i>	Miscucho	I, V	I, VII
53	R10-189	<i>C. annuum</i> var. <i>annuum</i>	K149992	II, VII	V, VII
54	Red mushroom	<i>C. annuum</i> var. <i>annuum</i>	Red mushroom	V, VII	VII

22–25°C for a 16 h photoperiod. For FESEM observation, sixth leaves (10 mm × 10 mm) and 3rd stem internodes (150 mm) were harvested from 7 week-old pepper plants.

Analysis of trichome morphology. For analysis of trichome morphology and size, FESEM (SUPRA 55VP, Carl Zeiss, Oberkochen, Germany) was performed in NICEM, Seoul National University, without processing of samples in low-vacuum mode. The samples were monitored with a 15-kV accelerating voltage, and photographic images were captured digitally.

FESEM micrograph of the trichomes of *Capsicum* species. FESEM observation of 54 germplasms of 6 different chili pepper species identified 6 different types of trichome on the epidermis of stems and leaves, and described in detail and summarized in Fig. 1 and Table 2. The FESEM micrographs observed on the epidermis of pepper stems and leaves with magnification through 250, 500, and 1000 were presented and glandular cell, non-glandular cell, and multicellular base were indicated with arrows (Fig. 1).

Glandular type trichome. Three glandular type trichomes (type I, IV and VII) and three non-glandular type trichomes (type II, III, and V) were observed in the epidermis of chili

pepper compared to known trichome types in tomato (Fig. 1 and 2). Six different types of pepper trichomes were also illustrated based on the observation under FESEM (Fig. 2). Glandular trichomes were characterized by the gland on the tip of trichomes and further classified according to the cellular base and cellular stalk. Type I glandular trichomes had typical structure of a multi-cellular base, a long (~2 mm) multi-cellular stalk, and a small glandular tip (Fig. 2-I). Type IV glandular trichome has a smaller glandular tip with single or 2-celled base and stalk shorter than type I (~0.3 mm) (Fig. 2-IV). In contrast, type VII glandular trichomes contain a short (< 0.05 mm) unicellular stalk and has an 8-celled gland on the tip of trichome (Fig. 2-VII).

Non-glandular type trichome. Non-glandular type trichomes on the chili pepper epidermis has simpler shape and no gland was observed on the tip of the trichome. Type II non-glandular trichome has a multi-cellular base and are ranged from 0.2 to 1.0 mm in length (Fig. 2-II). Type III non-glandular trichomes were similar in length (0.2–1.0 mm) with type II, and has distinct unicellular base (Fig. 2-III). However, type V non-glandular trichomes were shorter (0.1–0.3 mm) in length and fored on a unicellular base (Fig. 2-V). Non-glandular and short trichomes existed on the main stem and had small bumps on the trichome surface.

Fig. 1. FESEM micrograph of the trichomes on the epidermis of *Capsicum* species. Epidermal surface of stem (I-III and V). Adaxial surface of leaf (IV). Abaxial surface of leaf (VII). I. Trichome type I has glandular cell and multicellular base that are indicated by white arrows. II. Trichome type II has non-glandular cell and multicellular base that are indicated by arrows. III. Trichome type III has non-glandular cell and unicellular base. IV. Trichome type IV has glandular cell and unicellular base. V. Trichome type V has non-glandular cell and unicellular base. VII. Trichome type VII has 8-celled glandular cell and unicellular base.

Characteristic features of trichomes on the genus *Capsicum*. In the species *C. annum*, type II, III, V and VII trichomes on the stems and only type V and VII trichomes on its leaf surface were observed. However, in the species of *C. chinense*, type I and V were observed on stems while type I and VII were observed on leaves. In *C. frutescens*, type V and VII on stems and type VII on leaves were observed. Only type IV and VII trichomes on stems and leaves of *C. pubescens* were observed. However, the species

C. baccatum had type II, V, and VII on the stems and leaves (summarized in Table 3). Type VII trichomes were commonly observed on leaves of all tested five pepper species. However, in each species different types of trichomes were often observed on stems and leaves.

From the observation of trichomes in 5 pepper species including 54 accessions, we found that pepper trichome type VII was different from tomato trichome type VII. Type VII on a tomato has 4–8 cell gland while pepper type VII

Fig. 2. Illustration of epidermal trichomes on the genus *Capsicum*.

Table 2. Type of trichomes on the epidermal surface of the genus *Capsicum*

Type	Base	Stalk length (mm)	Stalk	Glandular
I	Multicellular	~2	Multicellular	+
II	Multicellular	0.2–1.0	Multicellular	–
III	Unicellular	0.2–1.0	Multicellular	–
IV	Unicellular	~0.3	Multicellular	+
V	Unicellular	0.1–0.3	Multicellular	–
VII	Unicellular	~0.05	Unicellular	+ (8 celled)

Table 3. Characteristic features of trichomes on the genus *Capsicum*

Species	Trichome types on stems	Trichome types on leaves
<i>C. annuum</i>	II, III, V, VII	V, VII
<i>C. chinense</i>	I, V	I, VII
<i>C. frutescens</i>	V, VII	VII
<i>C. pubescens</i>	IV, VII	IV, VII
<i>C. baccatum</i>	II, V, VII	II, V, VII

trichome has only 8 cell glands on stems and leaves. Type VII trichome appears to be present on the all epidermal surfaces of pepper plants for preventing physical damage from insects and animals. *C. annuum* CM334 had high density trichome on whole plant surfaces. Trichome-formation on pepper cultivar CM334 is known to be associated with resistance against *Phytophthora capsici* and viruses

(Kim et al., 2010). However, our results revealed that CM334 had only nonglandular type of trichome on the stems and leaves.

There are two types of trichomes, occurrent form and permanent form, during plant growth (Lee, 2000). Plants developed a variety of trichomes on the entire surface of the plant and there are different types of trichomes on the plant parts (Esau, 1979; Werker, 2000). In this study, we observed that type I, IV, and VII glandular trichomes produce volatile secondary metabolites based on flavors following breakage of trichome by touch. Type II, III, and V are non-glandular and known to have associated with defense functions (Kim et al., 2010; Kim et al., 2011). Glandular trichomes produce a diverse array of compounds that provide direct or indirect protection against herbivores and pathogens (Duffey and Isman, 1981; Elle et al., 1999). In Solanaceous plants, these compounds include terpenes, acyl sugars, alkaloids, and defence-related proteins (Antonious and Snyder, 2006; Duffey, 1986; Shepherd and Wagner, 2007). The mono- and sesquiterpene compounds identified here are most probably synthesized in the plastid and cytosol, respectively (Besser et al., 2009; Sallaud et al., 2009). There are quite a few types of glandular trichomes in many plant species. (Hallanhan et al., 2000; Kolb and Müller, 2004). Glandular trichome is similar to non-glandular trichomes but glandular trichomes has the appropriate shape change or specialization for secretion. In this study, glandular trichomes on pepper plant type I and IV have secretion head and type VII has 8-celled head on the trichome tip. Non-glandular trichome does not secrete anything while dried epidermal cells protects and prevents plants from UV and vaporizing, respectively (Karabourniotis et al., 1992, 1993). Extinct and dried trichome cells on plant epidermis reflect and disperse sunlight. Also, these trichome on dried cells prevent insect attacks by pricking insects and caterpillars (Lee, 2000).

Among the chili pepper germplasms, *C. chinense* and *C. pubescens* have glandular trichomes type I, IV, and VII. However, the pepper germplasms belonging to *C. annuum*, *C. baccatum*, and *C. chacoense* do not have type I and IV nor have any scent. Further works on secreted metabolites from type I, IV, and VII trichomes on pepper could provide valuable information for understanding the roles of trichome-derived secondary metabolites in herbivore tolerance of plants. Furthermore, ongoing researches for map-based cloning of the trichome-forming locus *Pt11* in chili pepper will also provide an insight and clues for explaining the association of trichome and multiple disease resistance in chili pepper plants.

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