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Trichome as the natural biophysical barrier for plants and its bioinspired applications

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Abstract: Nature has inspired mankind with novel inventions on biomimetic structures and materials, where plants provide a significant source of inspiration. Plants have evolved a range of effective appendages, among which trichomes have attracted extensive research interests due to their enormous functions. It is important to understand trichome functions and corresponding mechanisms for their bioinspired applications. In this review, we provided a comprehensive overview of the diverse functions of trichomes, with emphasis placed upon their roles as biophysical barriers which can create a complex three-dimensional (3D) network to help plant adapt to severe environments. Moreover, we also summarized the bioinspired applications about four typical trichomes, inclduing needle-like, hook-like, foliar-like and antenna-like trichomes. This review offers a new perspective of interdisciplinary research both on trichomes functions and their biomimetic applications.

Keywords: Needle-like trichome, Hook-like trichome, Foliar-like trichome, Bioinspired applications

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1. Introduction

Nature has bred various creatures (*e.g.*, animals, plants and bacteria) with well-adapted structures and materials from macroscale to nanoscale after billions of years of evolution.[1-3] These creatures have provided inspirations for mankind with a series of novel inventions and creations on biomimetic structures and materials, providing effective solutions to many scientific and technical issues.[4-7] Among these creatures, plants are a significant source of inspiration because they have evolved with great skills such as adaptive behavior and growing permanent structures like trichomes and thorns.[8] For instance, inspired from the way plant leaves convert solar energy into chemical energy, scientists have designed solar cells and solar panels.[9] To survive in extremely arid environments, cactus has evolved highly efficient water conservation and collection systems, which inspired researchers to design and fabricate functional materials and devices with water collection ability.[10-16] White feathery pappi, distal to dandelion seeds that are noted for aiding dandelion seed dispersal and germination by collecting water droplets, have inspired researchers with novel open fibrous systems for highly efficient liquid transfer.[17-19] Inspired by lotus leaves that exhibit excellent self-cleaning properties, scientists have fabricated a lot of biomimetic superhydrophobic surfaces for widespread applications.[20-24] Velcro, whose emergence has a profound impact on human life, is also inspired by burdock seeds with small hooks that enable these seeds cling stubbornly to the tiny loops in the fabric of human clothing (**Fig. 1**).

Among the specialized structures of plants, trichomes have attracted special interest because they are one of the most powerful defense appendages, not only creating a complex three-dimensional (3D) network to help plant adapt to severe environments, but also secreting fluids (exudates) to provide biochemical defenses.[25-31] Trichomes are differentiated epidermal cells widely distributed on the surface of most plants (ranging from ferns to angiosperms) and could be either unicellular or multicellular.[32-34] Although trichomes exhibit diverse structures and morphologies,[33, 35] they are normally grouped into two general categories, *i.e.*, glandular trichomes that

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can store and secret copious amounts of chemical substances to resist insect[26] and non-glandular trichomes that mainly act as deterrent and provide plants with biophysical barriers.[27, 28] Compared with glandular trichomes, non-glandular trichomes have attracted more attentions from biomimetic researchers owing to their intriguing structures and powerful biophysical functions. Non-glandular trichomes vary from soft hairs to rigid hooks or sharp stalks, with common structural forms such as needle-like, hook-like, foliar-like and antenna-like. Various functions have been ascribed to non-glandular trichomes in a wide range of plants, including but not restricted to reducing water transpiration, fog collection, increasing tolerance to abnormal temperature, and protecting plants against UV radiation and insect herbivores.[36-39] Inspired by these special functions of non-glandular trichomes, biomimetic structures originating from trichomes have attracted increasing attention in both basic research and industrial applications, especially with recent advances in micro/nanotechnolgies and novel materials. For example, inspired by trichomes (also termed as spines) covered on cactus stems, fog collector has been developed to overcome the crisis of global water shortage.[10] Inspired by hook-like trichomes of *Galium aparine*, researchers have duplicated the stem, leaf, and mericarp surfaces to mimic their adhesive behaviours using epoxy resin replica moulding technique.[40] For these bioinspired applications of trichomes, it is important to understand trichome functions and corresponding mechanisms.

The growing number of studies focusing on bioinspired applications of trichomes calls for a review paper focusing on such subject to offer more inspiring ideas for scientists and bioengineers. Although there exist a few good review papers about trichomes, they mainly focus on the molecular mechanisms of trichome initiation and differentiation and there is a lack of a review focusing specifically on functions of trichomes and their bioinspired applications, which is the thrust of this review. In the current review, four typical types of non-glandular trichomes as well as their corresponding bioinspired materials and structures are discussed, including needle-like, hook-like, foliar-like and antenna-like, respectively. Generally, trichome

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is a powerful appendage of plants, the bioinspired applications of trichome has given rise to new technologies at macroscale or nanoscale. Thus, the more studies focus on their functions and corresponding mechanisms, the more bioinspired applications based on trichomes could be designed and fabricated.

2. Needle-like trichomes and their bioinspired application

Needle-like trichomes, also named as spines, are mainly found on cactus. Most cacti live in some drought area or extremely dry environments (*e.g.*, Atacama Desert).[41, 42] To survive in such harsh environments, cactus has evolved high efficient water conservation and collection systems.[10] For instance, almost all cacti have thickened and fleshy parts of stem with different shapes (**Fig. 2a&c**), which is succulent and adapted to store water. To reduce the amount of evaporation, cacti have lost their true leaves, retaining only needle-like trichomes (**Fig. 2b&d**). In general, needle-like trichomes array defend against herbivores and help prevent water loss through reducing airflow around the stem of cactus. Currently, increasing interest has been placed on the new functions of needle-like trichome, such as water collection from fog and its bioinspired application. From the perspective of structures, needle-like trichomes grow as clusters on the surface of stem (**Fig. 2b&d**). These needle-like trichomes grow as a hemisphere in different directions with thousands of micrometers in length and several tens of micrometers in diameter (**Fig. 2e**). Based on the SEM images of individual trichome (**Fig. 2f**), it contains three different structural features, *i.e.*, oriented barbs in the tip region, gradient grooves in the middle region, and belt-structure in the base region (**Fig. 2f**). The magnified image also reveals a conical shape with aligned grooves. There is a gradient in width on the surface grooves along the length, from the end of base (**Fig. 2g**) to the end of tip (**Fig. 2h**). Some theories have been proposed to explain the mechanisms for water collection from air. Jiang's group revealed the relationship of the fog collection function of cluster-distributed trichomes and their surface structural features.[10, 43, 44] They found that the gradient of multi-function integration, surface-free energy and Laplace pressure contribute to the fog collection system of cactus. Firstly, a drop moving on the conical trichome is

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driven by the gradient of Laplace pressure. The Laplace pressure difference between the two sides of a droplet is generated as a result of the different trichome radii at two sides of the drop, which drives the movement of the drop to the base end of trichome with a larger radius (**Fig. 2i&j**). Secondly, there is a gradient of surface roughness because microgrooves on the surface become increasingly sparser along the length of trichome, which results in a gradient of wettability and surface-free energy, producing a driving force (F) to move water drop towards the end of base.

The deposition and collection of water droplets at micron scale by cacti have inspired researchers to design more effective devices, such as micron scale oil droplets collection systems. To meet the demand of environmental protection and petroleum industry development, Li *et al.* have fabricated an efficient oil collection system, which mainly includes an oleophilic rough conical polydimethylsiloxane (PDMS) needle array (Fig. 3a). Underwater, the conical needle arrays can achieve efficient collection of microscale oil droplets and can directionally and continuously transport them towards the base of the needles.[45]

Besides, the efficient fog collection system in cactus also provides inspiration for mankind to design and fabricate novel functional materials and devices with water collection ability.[41] Motivated by fog collection principle of cactus, Ju *et al.* constructed a gradient wettable material through an electrochemical procedure to engender efficient and continuous fog collection.[15] To prepared conical copper wires (CCWs), they mainly have the aid of gradient electrochemical corrosion and chemical modification. Efficient drop transportation and collection arrays were obtained mainly benefiting from the gradient of wettability and the gradient of Laplace pressure on the hydrophobic tip of the CCWs. The bioinspired gradient wettable CCW may provide new ideas and directions to design fog-collection devices.[41]

Inspired from water collection found in the cactus, Heng *et al.* developed an artificial water-collection structure composed of an array of small ZnO wires (100 μm in length)

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around a large ZnO wire (1 mm in length).[46] All these wires exhibited conical shapes with diameter decreasing from the root to the tip. Accordingly, the capillary force induced by the diameter gradient could drive water drops condensed on the tip and move to the root.[41] They compared the amount of water collected by cactus and artificial ZnO wires and found much better water collection ability from the artificial structures (1.4-5.0 times higher). The artificial structure can efficiently collect about 6 μL water in 30 min.

Inspired by the phenomenon that on the cactus stem, cones were densely distributed between the clusters of trichome,[12] Ju *et al.* fabricated PDMS cone arrays through mechanical perforation and replica molding methods. To prepare PDMS cone arrays, stainless steel needles were used to punch holes on a low-density polyethylene (LDPE) sheet, and then PDMS was used to replicate the structures. They demonstrated that the hexagonally arranged PDMS cones exhibited enhanced water collection capability compared with tetragonal arranged cones.

Cao *et al.* designed and fabricated a novel cactus-inspired fog collector using a modified magnetic particle-assisted molding method (MPAM) by using the blend of PDMS and cobalt magnetic particles (Co MPs) under the external magnetic field.[13] Cactus needle-like conical micro-tips were obtained with weight ratio of PDMS and Co MPs tuned to 2:1 (**Fig. 3b**). The water droplet driven by the Laplace pressure difference tended to flow towards the base of the needle-like cone. Additionally, the authors integrated hydrophilic cotton matrix with the hydrophobic conical arrays and fabricated a simple, efficient and low cost water collect equipment at large scale, which can spontaneously and continuously collect about 3 milliliters water in 10 min. Such cactus-inspired fog collector holds great promise for applications in the regions where water is becoming an increasingly precious resource. Subsequently, Peng *et al.* developed a cactus needle-like magnetic array using the blend of PDMS and cobalt magnetic particles (Co MPs) using mechanical punching and template replica technology (**Fig. 3c**).[14] For this, they dispersed a certain amount of Co MPs uniformly

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into each hole of the arrays and added the PDMS into the template with the aid of a vacuum pump. Then, a permanent magnet was placed under the sample to make the Co MPs vertically distributed in the hole. The needle-like magnetic conical could vibrate periodically under external magnetic field and collect fog water spontaneously and continuously. Such magnetic fog collecting arrays might have potential applications in windless and foggy areas.[14]

Bioinspired structures have been fabricated to mimic the fog collection of cactus using electrochemical or chemical erosion of metal wires, or through the replica molding method. These materials and structures have promising applications in water scarcity regions.

3. Hooked trichomes and their bioinspired application

Hook-like trichomes are mainly found on the leaves and stems of catchweed bedstraw (*Galium aparine L.*), some bean plants (like *Phaseolus vulgaris* and *Phaseolus lunatus*) and *Mentzelia pumila*.[47-50] Particularly for catchweed bedstraw, whose fruit mericarp is covered by hook-like trichomes (**Fig. 4a-b**).[40, 48, 51] Furthermore, there exist three types of hook-like trichomes in *Mentzelia pumila* (**Fig. 4c-e**).

For catchweed bedstraw, the spiny bristles can discourage consumption of seeds by small birds.[48] Hook-like trichomes can also cling to the passing animals for long-distance transport of catchweed bedstraw seeds.[51, 52] In addition, catchweed bedstraw can take this unique ability of sticking to other plants as an ecological advantage to fight with competing plants. It is observed that the tips of hook-like trichomes may be broken when contacted by other organisms (*e.g.*, insects), and these broken tips can secrete some sticky de-esterified pectic mucilage and pectin, protecting the plants from further damage by sticking the insects.[51] For common beans, hook-like trichomes may be the most important morphological defense appendages. It has been observed that the legs of bed bug can be impaled by hook-like trichomes on *Phaseolus vulgaris*, and the number of killed insects like leafhoppers

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were correlated with trichome density on *Phaseolus lunatus*.[49, 50, 53] In addition, hook-like trichomes can hinder germ tubes of rust to reduce the susceptibility of plants. This is further confirmed by the negative correlation between leaf pubescence and intensity of rust infection found in bean, classified as race-nonspecific resistance.[49, 54] For *Mentzelia pumila*, different types of hook-like trichome exhibit different ways to defend against insect pests. The first and third types of trichome can be mainly taken as grappling devices (**Fig. 4c&e**), just like the hooking behavior of hook-like trichomes on common beans, whereas the second type of trichomes can not only restrain the insects but also perforate them (**Fig. 4d**). Further, some insects could be held and entrapped in the spaces of trichomes, resulting in limited movement and even death of these insects (**Fig. 4f&g**). It has also been observed that hook-like trichomes can injure the eggs of insects (**Fig. 4h**). Although there is no direct visual evidence to prove the piercing behavior of the second type of hooked trichome, it was reported that trapped insects were injured when captured as shown by the released blood (**Fig. 4i**).[47]

Inspired by hook-like trichomes on *Galium aparine*, a plant known for the ability to adhere to subjects through its hook-like trichomes, Hayley *et al.* duplicated the stem, leaf, and mericarp surfaces of *Galium aparine* to mimic their adhesive behaviours using epoxy resin replica moulding technique.[40] Furthermore, inspired by physical entrapment of bed bugs or leafhoppers by hook-like trichomes on kidney bean leaves, Megan *et al.* fabricated surfaces covered with hook-like trichomes through molding the kidney bean leaves (**Fig. 5**).[55] Compared with the real leaves, the biomimetic structures can only temporarily snag the bed bugs rather than impede their movement, which indicating that future development of biofabricated hook-like trichomes should consider the mechanical property of trichomes. With the resistance to pesticides widespread, bioinspired structures which mimic physical defense of plant trichomes against pests have the potential to replace chemical pesticides in agriculture to meet the need of environmental protection and sustainable development.[56]

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4. Foliar-like trichomes and their bioinspired application

Stem and leaves of *Tillandsia* species (*e.g.*, *Tillandsia velutina* and *Tillandsia usneoides*) are covered with dense, overlapping and multicelluar trichomes, named as foliar trichomes. The most prominent feature of *Tillandsioid* trichomes is highly elongated wing cells. The center of the shield consists of four heavily cutinized central disc cells on the distal surfaces. The stalk cells are adjacent to the central disc cells and can connect the central disc cells with mesophyll cells as a channel (**Fig. 6a, b, d**).[57-59] Researchers have revealed that many epiphytic bromeliads of the atmospheric-type morphology can absorb water vapor and nutrients directly from the highly humid air.[59, 60] Previous studies have hypothesized that *Tillandsia* trichomes can conserve more water and reduce transpirational water loss by increasing the leaf boundary layer thickness.[61]

For bioinspired applications of foliar trichomes, *Tillandsia capillaris* can act as an efficient bioindicator of atmospheric metal and metalloid deposition. For instance, *Tillandsia capillaris* has been used to monitor the contamination levels of metal and metalloid deposition in three regions for five months.[62, 63] Metal particles were detected on the surfaces of *Tillandsia* and the central disc of foliar trichomes. X-ray absorption spectroscopy indicated that arsenic was transformed into plants and oxidized from As^{III} to As^{V}.

Tillandsia species can adsorb nutrients and water through leaves directly from the ambient air, which enables them to effectively and rapidly abate air pollutants (*e.g.*, formaldehyde (FA)), pledging *Tillandsia* species a promising candidate for indoor air purification. To uncover the role of trichomes in such air cleaning process, plants with different removal degrees of foliar trichomes were put in chambers filled with FA.[57] The results showed that plants with foliar trichomes can decrease the concentration of FA by 48.42% in 12 h, whilst those without trichomes decreased FA concentration by only 22.51% during the same period (**Fig. 6c**), indicating that the specialized trichomes that densely cover *Tillandsia* leaves could facilitate the whole leaf tissue

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absorption of FA. Moreover, foliar trichomes were also reported to absorb Hg contamination. Non-contaminated *Tillandsia usneoides* were exposed to the atmosphere with Hg for 15 days, and then energy-dispersive X-ray analysis (EDXA) analysis demonstrated that Hg was mostly absorbed by foliar trichomes (**Fig. 6d**).[64]

5. Antenna-like trichome

Antenna-like trichomes, found mainly in *Arabidopsis*, are non-glandular and simple unicellular protuberances surrounded by accessory epidermal cells on both sides of leaves, stems, and sepals.[65] They usually exhibit antenna-like morphology with three to four branches (**Fig. 7a-b**). Because trichomes in *Arabidopsis* are easily obtained and observed, they have been regarded as ideal models to study many aspects of cell morphogenesis from the view of cell biology and molecular genetics.[66, 67] Trichome initiation is integrated with leaf development as well as plant vegetative development phase.[68] It is highly regulated for epidermal cells to acquire the trichome fate. For example, on leaves, trichome differentiation begins at the leaf distal tip when the leaf grows to approximately 100 μm long,[69] and proceeds basipetally. While leaf epidermal cells continue to divide, cells dedicated to trichome fate will stop cell division but keep replicating its genomic DNA.[70-72] Then, the incipient trichome begins to expand from the leaf surface and initiates two consecutive branching events.[33] After branch differentiation, another growth phase begins, mainly including fast vacuolization along with rapid expansion of branches and the formation of papillae.[73] It has been reported that mature leaf trichomes are about 200-500 μm tall and 40-60 μm wide.[74, 75] Trichomes are distributed with an average distance of about three cells in Arabidopsis and it is rare to find trichomes located adjacent to each other.[76, 77]

It has been reported that Arabidopsis trichome can act as an active mechanosensor, mainly benefiting from its non-uniform cell wall thickness, and gradient mechanical properties of cell wall.[78, 79] When insects alight or crawl on the leaves of Arabidopsis, trichomes on the surface could be mechanically disturbed, which transduce

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mechanical signals into physiological response mainly through eliciting a buckling instability on the base of trichome and focusing the mechanical force to the plaint zone.[79] Such buckling instability can elicit cytosolic calcium oscillation and apoplastic pH vibration.[79] From the view point of mechanical properties, the Young's modulus of trichome cell wall was found to increase gradually from the base region to the branches of trichome.[78] Such gradient distribution of Young's modulus can significantly promote force focusing and buckling instability on trichome base (**Fig. 7c**). Moreover, trichomes could further increase leaf surface roughness and boundary layer depth, which may contribute to conducting heat from the leaf surface and enhancing heat exchange across the surface, and hence protect the plant from injury induced by high temperature.[80, 81] In addition, from the material perspective, crystalline cellulose, a main component of secondary cell wall of trichome, can reflect bright light to defend plants from photodamage or optical radiation.[82, 83]

6. Concluding remarks and future perspectives

To survive in a tough environment, natural creatures have evolved with unique properties, which make them exhibit coordination and harmonization between structure and function. Inspired from nature, more biomimetic materials and structures deserve exploitation in depth. Among natural creatures, plants are a significant source of inspiration because they have evolved with great skills such as adaptive behavior and growing permanent structures like trichomes and thorns. Trichomes, as important first defense lines against herbivorous insects and pathogens, have recently attracted significantly increasing research attention. Trichomes vary in location, morphology and secretion ability, while they are normally defined as two general categories, *i.e.*, non-glandular trichomes and glandular trichomes, responsible for biophysical and biochemical defense functions respectively. Non-glandular trichomes vary in morphology, such as needle-like trichomes, hook-like trichomes, foliar-like trichomes, antenna-like trichomes and so on. Accordingly, inspired by these special structures and functions of non-glandular trichomes, biomimetic applications originating from trichomes have attracted increasing attention in both basic research and industrial

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applications. Such as Velcro inspired by burdock seeds with small hook-like trichomes, fog collecters from needle-like trichomes on cactus.

Although tremendous progress in the fields of genetics and molecular biology have allowed for the discovery of genes involved in trichome morphology, density and trichome produced compounds,[31, 84-86] the potential benefit of trichomes to plants has not been completely exploited since the environment of plants is complex.[87] For instance, trichomes in Arabidopsis, which belong to the non-glandular type and mainly play an important role in biophysical defense, can also convert physical signals such as mechanical touch from insects into chemical signals like calcium oscillation and pH shift of skirt cells to elicit various defensive reactions of Arabidopsis.[79] Besides, not only non-glandular trichomes can provide both biophysical and biochemical defense, glandular trichome can also act as biophysical barrier besides secreting chemical compounds. Furthermore, glandular trichomes and non-glandular trichomes can work together to accomplish many important biological events in nature, such as plants adaptation to harsh environments. Luca *et al.* have reported that on the leaves of *Lychnophora diamantinana*, non-glandular trichomes can protect young organs against desiccation mainly by deposition of highly hydrated and viscous metabolites on the apices. Meanwhile, glandular trichomes secrete phenolic compounds and terpenoids which might be beneficial for plants to repel herbivore and pathogen attacks, providing *L. diamantinana* a more healthy and comfortable environment to survive in drought.[88]

Learning from nature, especially plants, humans have developed various inventions and creations, like solar cells and propeller UAV (unmanned aerial vehicle). Trichomes as vital appendages for plants against severe environment, should be further studied from multi-perspective and interdiscipline to dig out their potential important roles not only in plant defense, but also in bionic technology and applications. Thus, with fast development of interdisciplinary research and broad applications of biomimetics, not only non-glandular trichomes, glandular trichomes

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should be concerned as well. That's because, glandular trichomes can store or secrete a wide variety of secondary metabolites, including terpenoids, acyl sugars, flavonoids and defensive proteins.[89-93] These metabolites have been found to provide the plant with biochemical protection through repelling herbivores or pathogens.[26, 94] Biomimetic applications of these metabolites might reduce the harm to human health and environmental pollution of chemical pesticides, which will benefit the environmental protection.

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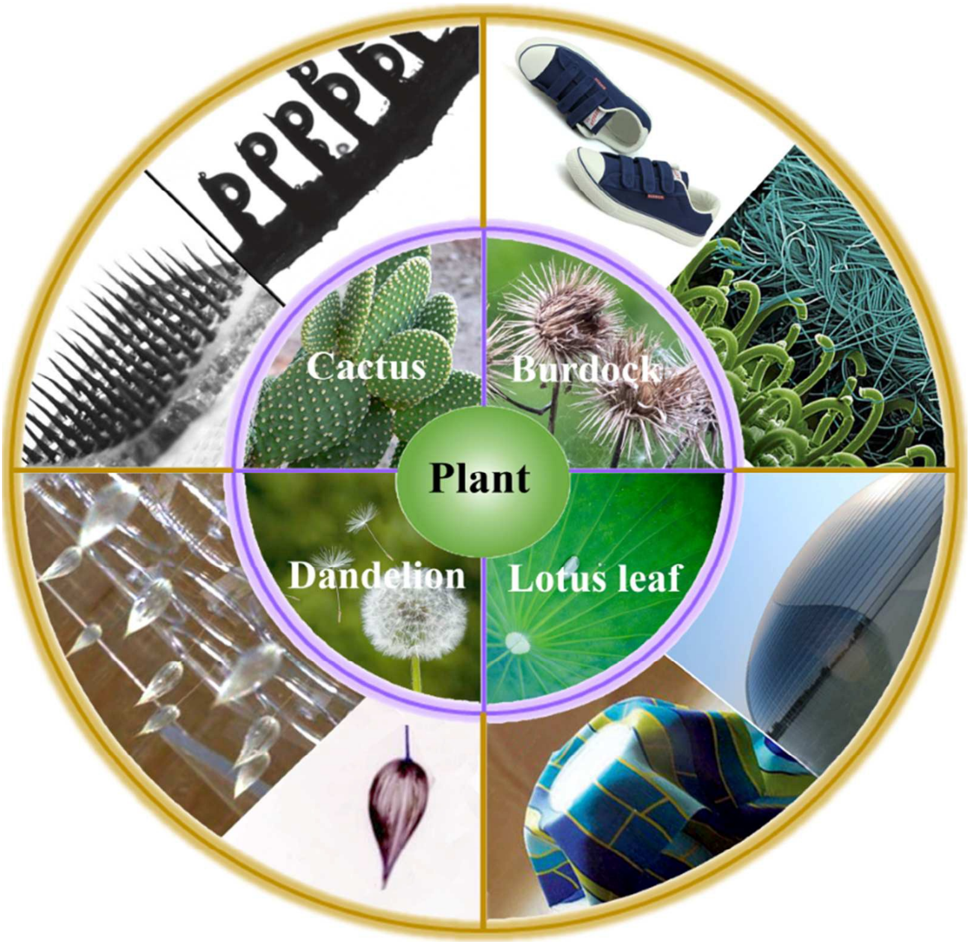

Fig. 1 The most representative examples of bioinspired applications of plants. Cactus has high efficient water conservation and collection systems, inspiring from this, functional materials and devices with water collection ability were designed and fabricated; Distal to dandelion seeds, white feathery pappi are noted for aiding dandelion seed germination by collect water droplets, have inspired researchers with novel open fibrous systems for highly efficient liquid transfer by capturing and holding water steadily; Lotus leaves exhibit excellent self-cleaning properties, inspiring from this, scientists have fabricated a lot of superhydrophobic surfaces on buildings or textiles. Velcro has a profound impact on human life, which is inspired by burdock seeds with small hooks.[13, 14, 19, 21]

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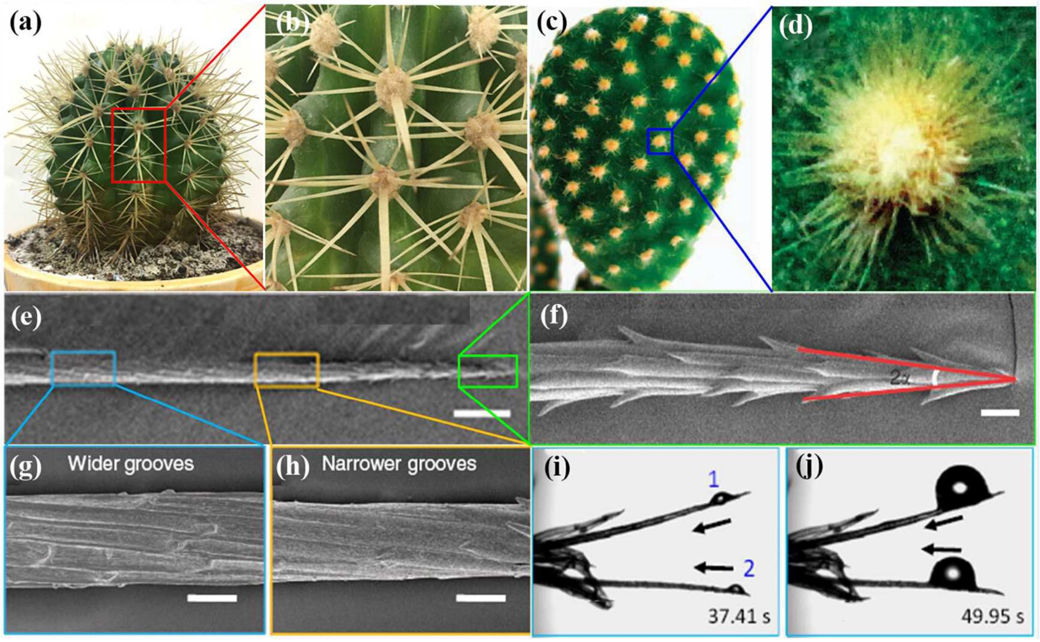

Fig. 2 Structures of needle-like trichome. (a) The stem of a ball-shape cactus. (b) The cluster of cactus trichomes on a ball-shape cactus. (c) The stem of a pie-shape cactus. (d) The cluster of cactus trichomes on a pie-shape cactus. (e) SEM image of the multi-level structures of a single spine of cactus trichome (Scale bar: 20 μm). (f) Magnified SEM image of the tip of a single spine of cactus trichome (Scale bar: 2 μm). (g) Magnified SEM image of the wider grooves of cactus trichome (Scale bar: 2 μm). (h) Magnified SEM image of the narrower grooves of cactus trichome (Scale bar: 2 μm). (i-j) The movement and converging of water drops from two adjacent spines of cactus trichomes, the black arrows depict the moving direction of water drops.[10] The images are reproduced with permission as follows: (c-j) from REF.10 © 2012, Nature Publishing Group.

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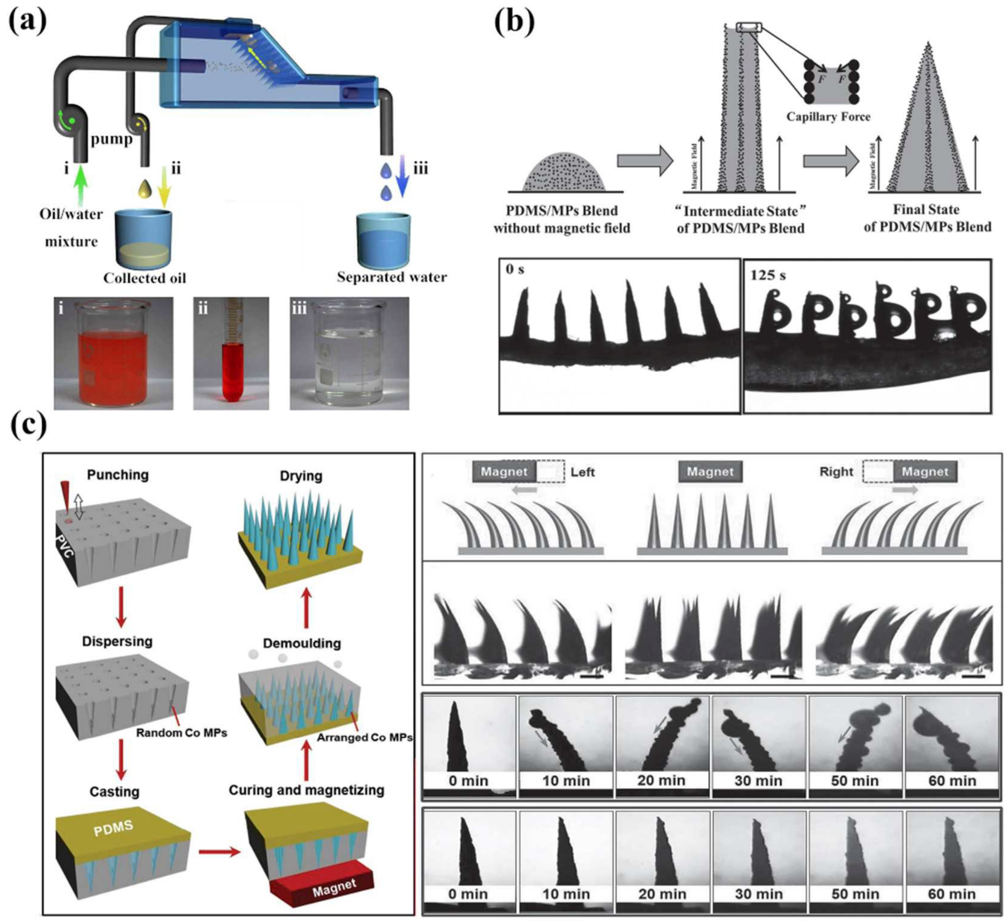

Fig. 3 Examples for the fabrication of cactus-inspired conical arrays. (a) Schematic of oil droplet collection system. When oil and water mixture (i) were sprayed to the conical needle array, oil droplet were collected by needle array (ii), while water flowed through a tube below (iii).[45] (b) The diagram of the conical needle formation mechanism and efficient fog collection ability. Conical arrays were fabricated when the blend of PDMS and MPs under an external magnetic field.[13] (c) Schematic for the fabrication of magnetically conical needle arrays and their responses under an external magnetic field.[14] The images are reproduced with permission as follows: (a) from REF. 44 © 2013, Nature Publishing Group; (b) from REF.13 © 2014, John Wiley & Sons; (c) from REF. 14 © 2015, John Wiley & Sons.

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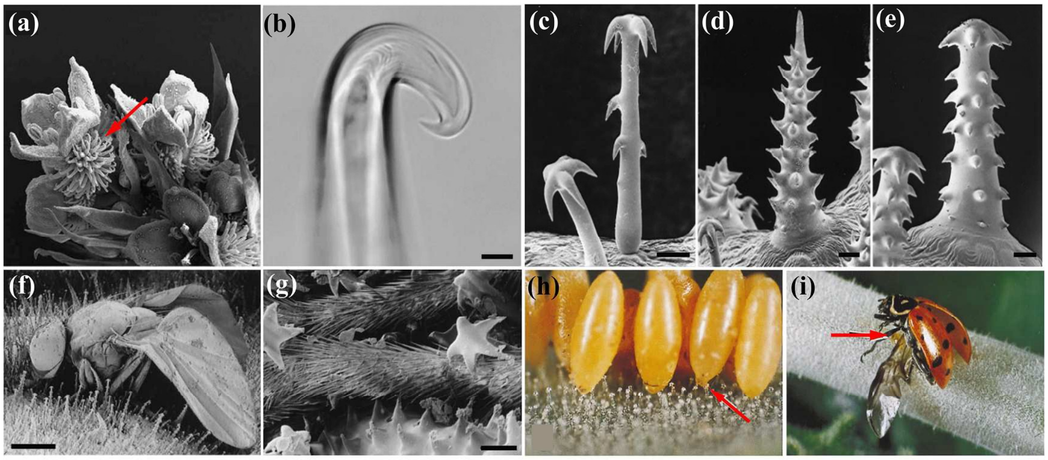

Fig. 4 Diverse structures of hook-like trichomes. (a) Scanning electron micrograph of the mericarp of catchweed bedstraw (*Galium aparine L.*) as denoted by the red arrow. (b) Details of the hook-like trichome from the mericarp taken through a stereo microscope (Scale bars: 20 μm).[51] (c-e) The first type (c), the second type (d) and the third type (e) of hook-like trichomes in *Mentzelia pumila*, (Scale bar: 20 μm). (f) An agromyza is entrapped on *Mentzelia pumila* surface (Scale bar: 0.05 mm). (g) The antennae of a sciarid fly are held in the space by hook-like trichomes on *Mentzelia pumila* (Scale bar: 20 μm). (h) A cluster of insect eggs are injured by hook-like trichomes on *Mentzelia pumila* as denoted by the red arrow. (i) The entrapped insect is injured with bleeding (marked by the red arrow) by hook-like trichomes on *Mentzelia pumila*.[47] The images are reproduced with permission as follows: (a-b) from REF.50 © 2008, Springer-Verlag; (c-i) from REF.46 © 1998, The National Academy of Sciences.

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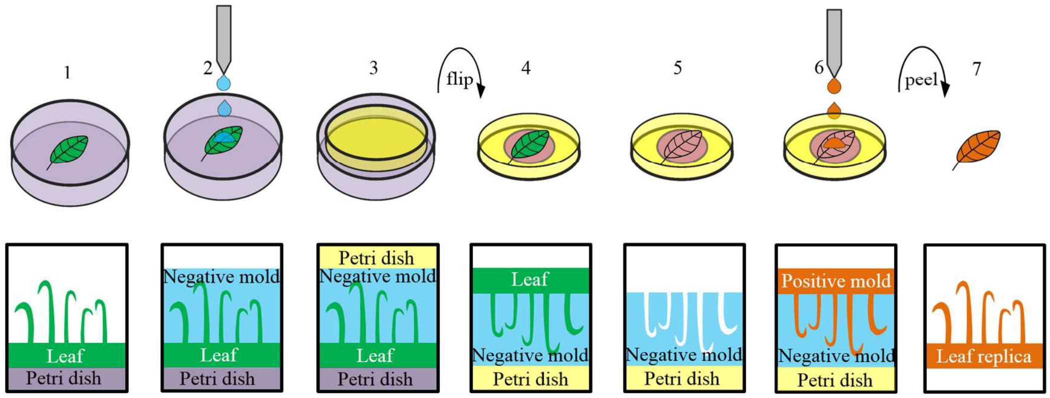

Fig. 5 Fabrication of bio-inspired hook-like trichomes of bean leaves. (1-3) The negative polyvinylsiloxane moulding material was poured onto a leaf surface, the Petri dish was placed and pressed on the top. (4-5) After removing the leaf, the negative mould was generated. (6-7) Positive replica material was poured into negative mould. After drying, negative mould was removed and leaving the leaf replica.[55]

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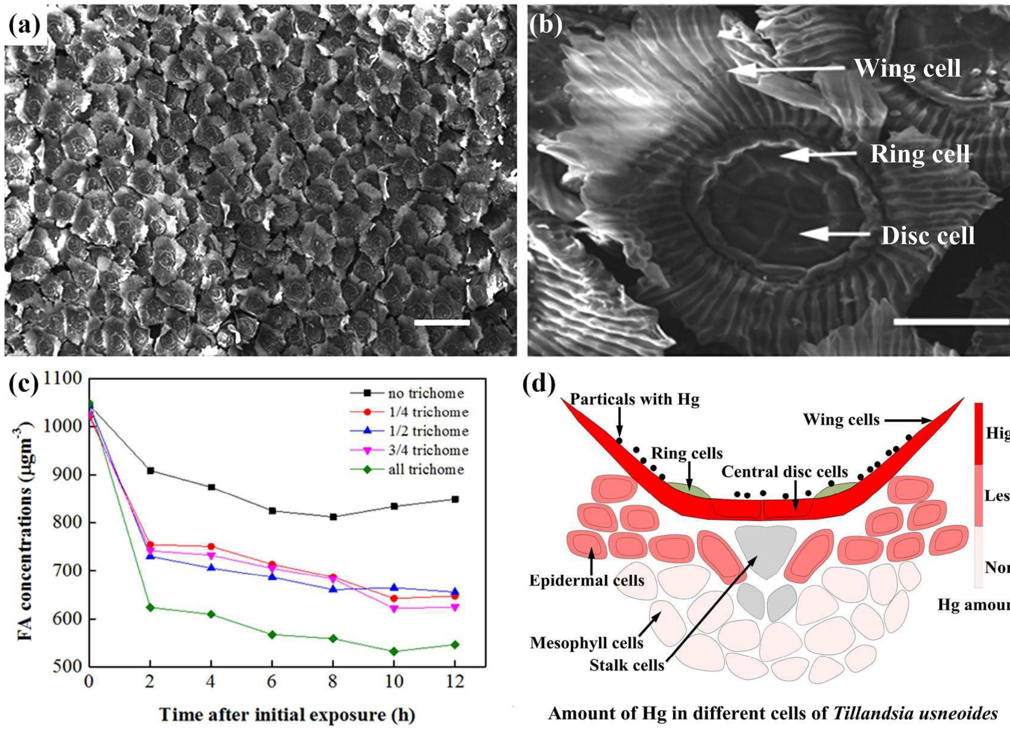

Fig. 6 Foliar-like trichomes and their bioinspired applications. (a) The leaf surface of *Tillandsia velutina* with foliar trichomes (Scale bar: 100 μm). (b) The structure of foliar trichomes on *Tillandsia velutina* (Scale bar: 10 μm). (c) Different formaldehyde (FA) concentrations in the chambers under different removal degree of foliar trichomes on *Tillandsia velutina*.[56] (d) Hg is highly absorbed by foliar trichomes, less absorbed by epidermal cells, and not absorbed by mesophyll parenchayma in *Tillandsia usneoides* based on the EDXA analysis.[64] The images are reproduced with permission as follows: (a-c) from REF.56 © 2014, Elsevier Ltd.

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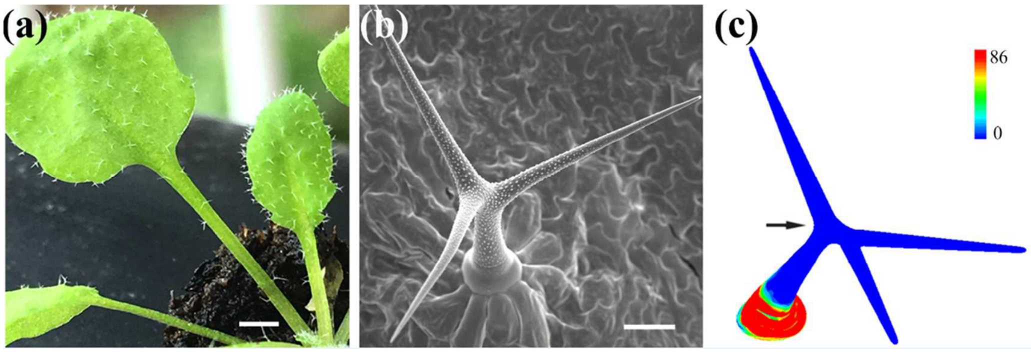

Fig. 7 Antenna-like trichomes on *Arabidopsis*. (a) Optical micrographs of trichomes covered on an *Arabidopsis* leaf (Scale bar: 5 mm). (b) Scanning electron micrograph of trichome (Scale bar: 50 μm). (c) Under shear force load (indicated by black arrow), the fictional trichome with gradient Young's modulus focuses force and buckles on the base region. The color scale in (c) represents the dimensionless strain energy density.[78]

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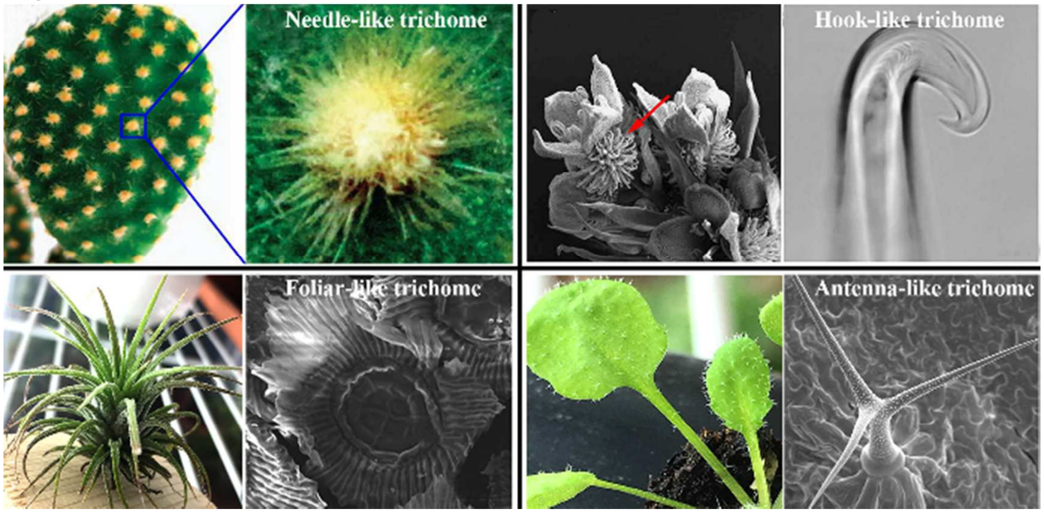
Figure: Various trichomes



The novelty of the work: This review offers a new perspective of interdisciplinary research both on functions of plant trichomes and their biomimetic applications.