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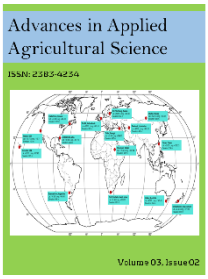

Review Article

Research Progress on the Laticiferous Canal of *Toxicodendron Vernicifluum*

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ABSTRACT

T. vernicifluum is an economic tree species which is also a specialty of China. The raw lacquer secreted by *T. vernicifluum* can be used directly as natural paint. The cultivation of *T. vernicifluum* and the utilization of raw lacquer have a centuries-old history. Laticiferous canal, which is mainly distributed in the phloem of the vascular bundle of each organ, secretes and stores raw lacquer. By reviewing the research results from the field of anatomy on the structure of the laticiferous canal and the phloem of *T. vernicifluum*, this paper discusses the structure and the development law of the components of laticiferous canal of *T. vernicifluum* for the purpose of providing theoretical basis for improving the yield and quality of raw lacquer and providing reference for the future studies on the secretory structure of plants.

T. vernicifluum is a kind of deciduous tree belongs to Anacardiaceae (Ze-Long 2009). Some of the *T. vernicifluum* are scattered in Southeast Asian countries like Thailand, Burma, Vietnam as well as other countries like Japan, North Korea and South Korea (Beaman 1986; Hong *et al*., 1999), *T. vernicifluum* and allied species have been introduced into parts of Europe, Australia and New Zealand, where they have caused allergic contact dermatitis (Rademaker & Dunffill 1995; José 2007). But they are mostly distributed in Shaanxi, Chongqing, Gansu, Hubei, Guangxi, Guizhou, Sichuan and Yunnan and other regions of China (Zhang *et al*., 2007). The cultivation of *T. vernicifluum* and the collection and application of raw lacquer have a history as long as thousands of years in China and other Asian countries (Kumanotani 1995; Vogl 2000; Webb 2000). The secondary metabolite secreted by laticiferous canals, raw lacquer, is a kind of quality natural paint and exhibit superior barrier properties against oxygen and water, as well as chemical resistence (Kim *et al*., 2009), some lacquer ware can preserve more than one thousand of

years (Li *et al*., 2009). The main part secreting and storing raw lacquer is the phloem of each organ of *T. vernicifluum*. The traditional method of collecting raw lacquer is to unrip the bark of the tree trunks into cuts of different shapes where the raw lacquer can flow out and be collected (Vogl *et al*., 1994). Since the 1970s, researchers have made a lot of studies on *T. vernicifluum,* including its distribution, germplasm resources, the structure of laticiferous canal and phloem, raw lacquer chemistry as well as other aspects (Zhang *et al*., 2007; Hong *et al*., 1999; Zhao *et al*., 2012; Fu *et al*., 2007; Yamauchi *et al*., 1982).

1 Research Progress on the Structure and the Development of the Laticiferous Canals of *T. vernicifluum*

1.1 The Distribution of the Laticiferous Canal of T. vernicifluum

The laticiferous canal of *T. vernicifluum* is the structure that synthesizes and stores raw lacquer. It can be divided into two categories: one is in the primary phloem germinated from the procambium, which is distributed in the phloem of various organs of *T. vernicifluum*; the medulla of the primary structure of the stem is also scattered with small-sized laticiferous canals (Fu *et al*., 2007). The other one is germinated from the vascular cambium, which is distributed in the secondary phloem of the stem in great deal; now it is the main part for raw lacquer collection (Wei *et al*., 2009). Previous studies on *pistacia chiensis* and other plants of Anacardiaceae have also shown that the secretory canals of most Anacardiaceous plants are distributed in the phloem of the vascular bundle of various organs (Venning 1948).

1.2 The Structure of the Laticiferous Canal of T. vernicifluum

Study on the microstructure of the laticiferous canals of *T. vernicifluum* in the phloem of trunks showed that the mature laticiferous canal is an oval or a circular cavity, which is generally distributed between the two phloem rays. The cavity is filled with raw lacquer. It is surrounded by secretory cells with dense protoplasm and the peripheral secretory cells are surrounded by 2 to 3-layer tabular sheath cells. Observed from the longitudinal section of the secondary phloem of bark, the laticiferous canal is in a microscler structure and its length is about 10 cm. Its extension direction is parallel to the long axis of the stem. Secretory cells and sheath cells can be observed clearly on both sides of the laticiferous canal (Zhao *et al*., 2012; Wang *et al*., 1979).

As the fruit of *T. vernicifluum* ripens, its exocarp and mesocarp will get atrophied and dried and the laticiferous canals of the fruit will turn into a special shape. As the ovaries develop into fruit, the secretory cells in laticiferous canals will get atrophied while the sheath cells will get developed (Fu *et al*., 2007). This distinct morphological characteristic maybe result from the atrophy of the parenchyma cells of mesocarp. As the fruit get ripe, the parenchyma cells of mesocarp will get atrophied and the laticiferous canals fail to secrete raw lacquer so that the cavity will endure a negative pressure, which prompts the volume of sheath cells to be enlarged to fill the depressed cavity.

1.3 The Development of the Laticiferous Canal of T. vernicifluum

Studies on the secretory canals of various plants show that, the development of secretory canals can be in three ways, namely, schizogenous way, lysigenous way and schizo-lysigenous way. In schizogenous way, the middle lamella of cell wall dissolves and cells separate from each other to form the secretory cavity. In lysigenous

way, secretory cavity takes shape from cytoclasis. As the name suggests, the schizo-lysigenous way is the combination of the first two ways (Fahn 1979). From the studies on the germination and the development of the laticiferous canals in the nutritive organs and reproductive organs of *T. vernicifluum*, we can easily get that the laticiferous canals of different organs are developed schizogenously and the development process of laticiferous canals can be divided into four stages according to the time sequence, namely: (1) archaeocyte (2) forming and expanding (3) mature (4) senescence (Zhao *et al*., 2012). The laticiferous canals of the organs of *T. vernicifluum* are developed schizogenously. In the primary structure of each organ, several rosulate archaeocytes of laticiferous canals are distributed outside the procambia, and then the middle lamella of cell walls will degrade to form up crena. The crena will expand in radical pattern between the each archaeocyte, the central position of rosulate cells separates and the primitive cavity takes shape, and the archaeocytes around the laticiferous canals will develop into secretory cells (Fu *et al*., 2005). In the development process of laticiferous canals, its diameter keeps enlarging. As the laticiferous canals are well developed, the quantity of epithelial cells can reach 25-40 (Zhao 2013).

The sheath cells in the laticiferous canals of *T. vernicifluum* are involved in secreting of raw lacquer. They contains the precursor substances of raw lacquer which are similar to epithelial cells (Hu & Zhao 1990); studies show that, in the primary structure of the sheath cells of the stem, part of the sheath cells can be developed into epithelial cells or invade into the existing epithelial cells (Zhao 2013). In this process, the enzymes contained in raw lacquer or in the precursor substances of raw lacquer may degrade the middle lamella, and participate in the invasive growth of the epithelial cell of laticiferous canals and the expansion and elongation of the cavity of laticiferous canal. In the raw lacquer secreted, enzymes account for 1-3%. Research results show that the main function of laccase is to realize the drying and filming of raw lacquer (Honda *et al*., 2008; Rong *et al*.,2004). Laccase contains many kinds of isozymes, but pectinases have not been separated yet (Wan *et al*., 2010). The functions of enzymes in the raw lacquer and in the epithelial cells in the forming process of laticiferous canals are subject to further study.

Ultrastructural studies on the forming process of the laticiferous canals of *T. vernicifluum* have shown that no osmiophilic substances exist in the archaeocyte of laticiferous canals and the abundant osmiophilic substances in secretory cells emerge with the formation and expansion of laticiferous canals. As the laticiferous canals get mature, osmiophilic substances in secretory cells will increase greatly and raw lacquer will be secreted in great deal; when the secretory cells of the canal get aging gradually, osmiophilic substances will be reduced and lacquer secretion stops (Hu & Zhao 1985; Hu & Zhao 1990).

2 Research on the Structural Feature of the Secondary Phloem of *T. vernicifluum* and the Relationship between the Structural Feature and Lacquer Secretion

2.1 The Structural Feature of the Secondary Phloem of T. vernicifluum

According to different regions and environments, the activity of cambium and the pattern of phloem can be in three types. Those native to temperate zone and Mediterranean are active in spring but dormant in fall; shrubs in tropical desert are active in rainy season of each year but dormant in dry season; trees grown in

subtropical zone or tropical zone have an active cambium all the year round (William & Evert 1967; Fahn & Werker 1990). Basic components of phloem are sieve molecules, phloem parenchyma, phloem fiber and stone cells; some others even possess laticiferous tube system and secretory canals (Evert 2006). The activity of the vascular cambium of *T. vernicifluum* stem is similar to that of majority dicotyledons in the temperate zone, and demonstrates the periodic activity routines of typical temperate trees (Zhao *et al*., 2012).

In the secondary phloem grown in the vascular cambium each year, sieve tubes get mature with the function of conduction; phloem parenchyma and phloem rays are still at the immature stage; laticiferous canals are in differentiation and development; this part is called functioning phloem. Outside the functioning phloem are the secondary phloem generated in previous years, of which the sieve tubes are atrophied without the function of conduction, so as to be called non-functioning phloem; It occupies most part of the phloem. As the parenchyma cells of non-functioning phloem increase in size, the sieve tubes will be pressed to collapse. In addition, in the non-functioning phloem, some parenchyma cells are differentiated into sclereid, and tylosoid will be produced in part of the laticiferous canal cavity to jam the laticiferous canals (Zhao *et al*., 2014). The structural and developmental characteristics of the phloem of *T. vernicifluum* mentioned above and its physiological functions could provide a scientific basis for collecting raw lacquer reasonably (Zhao *et al*., 2012).

2.2 The Influence of the Structure of Phloem on the Composition and Yield of Raw Lacquer

T. vernicifluum is the traditional tree species producing raw lacquer. After the maturation, laticiferous canals will synthesize and secrete raw lacquer in great deal (Hu & Zhao 1992). Researches on the structure, development and histochemistry of the phloem of *T. vernicifluum* show that, in the summer and early autumn, mature laticiferous canal cavity of the phloem is fully filled with raw lacquer; after entering the dormant period, the content of raw lacquer in laticiferous canal cavity is reduced (Wei *et al*., 2009). Therefore, for the main producing areas of raw lacquer in China like Shaanxi and its surrounding areas, collecting raw lacquer during June-August is in favor of lacquer production and consistent with the development law of the structure of the phloem and the cambium of *T. vernicifluum*.

In China, the main producing areas, such as Ankang and Shangluo of Shaanxi Province, lacquer collection usually adopts traditional method, namely unriping the bark of the tree trunks into cuts of different shapes, cutting off the laticiferous canals where the raw lacquer can flow out and collecting the raw lacquer with clamshell or other containers (Wang & Hu 1985). Lacquer collection and application has a centuries-old history in China, Burma, Vietnam, North Korea and other Asian countries (Honda *et al*., 2008; Webb 2000). Mature laticiferous canals are distributed in the non-functioning phloem mostly. For *T. vernicifluum* of different species, the differences in the quantity and the diameter of the laticiferous canals will influence their ability of secreting and storing raw lacquer, and thus affect the lacquer production (Hu & Zhao 1992). In addition, sieve tube is the transport channel of organic matter in plants and the matter transported may contain the precursor substances of raw lacquer, so the diameter size of sieve tube may also influence raw lacquer production. See from the analysis on the correlation between the diameter, quantity and thickness of laticiferous canals of different *T. vernicifluum* species and the yield of raw lacquer, a positive correlation is shown, which indicates that the

diameter, quantity and thickness of laticiferous canals are important factors for lacquer production (Zhao *et al*., 2013).

Raw lacquer is a kind of liliquoid secreted by the phloem of T. *vernicifluum* and collected from artificial cuts. Raw lacquer is mainly composed of urushiol, laccase, lacquer polysaccharide and water, and the proportions of these chemical constituents are (60%-70%), (5%-7%), (<1.0%) and (20%-30%), respectively (Hatada *et al*., 1994; Kim *et al*., 2009; Vogl *et al*., 1994; Yumin Du 1994). Urushiol is a mixture of catechol derivatives. It is constituted by the homologues of saturated urushiol, monoene urushiol, diene urushiol and triene urushiol, among which the triene urushiol accounts for the largest proportion. It is the basic reactant of lacquer curing and filming and the basic frame of the film, which directly affect the gloss, adhesion, toughness and other properties of the film (Kim *et al*., 2009; Niimura & Tetsuo 2006). Lacquer yield differs greatly among different varieties of *T. vernicifluum*, so does the proportion of urushiol homologues. In addition, the structural features of the phloem are also interrelated with the yield of raw lacquer and the content of triene urushiol (Zhao *et al*., 2013).

3 Research Prospects Related to *T. vernicifluum*

T. vernicifluum is an economic tree species which is also a specialty of China. The cultivation of *T. vernicifluum* and the application of raw lacquer have a history as long as thousands of years. The manufacture of lacquerware is also an important part of Chinese history and culture. Lacquer production is directly related to the structure of laticiferous canals which are mainly distributed in the phloem. Exploring the structure and the development law of the laticiferous canal and the phloem of *T. vernicifluum* will provide theoretical basis for improving the yield and the quality of raw lacquer and provide a reference for further studies on the secretory structure of plants.

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