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# Fiber Microstructure in *Solanum* Found in Thailand

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***Abstract*—**The study aimed to investigate characteristics of vegetative tissue for taxonomic purpose and possibly trend of waste application in industry. Stems and branches of 15 species in *Solanum* found in Thailand were prepared for fiber and examined by light microscopy. Microstructural characteristic data of fiber i.e. fiber length and width, fiber lumen diameter and fiber cell wall thickness were recorded. The longest average fiber cell length (>3.9 mm.) were obtained in *S. lycopersicum* L. and *S. tuberosum* L. Fiber cells from *S. lycopersicum* also revealed the widest average diameter of whole cell and its lumen at >45.5 µm and >29 µm respectively. However fiber cells with thickest wall of > 9.6 µm were belonged to the ornamental tree species, *S. wrightii* Benth. The results showed that the slenderness ratio, Runkel ratio, and flexibility coefficient, with potentially suitable for feedstock in paper industry fell in 4 exotic species, i.e. *Solanumamericanum* L.*,* *S. lycopersicum, S. seaforthianum* Andr., and *S. tuberosum* L

***Keywords*—**Fiber, microstructure, Solanaceae, *Solanum*.

## I. Introduction

*SOLANUM*, a genus of the family Solanaceae, is one of the largest genera of flowering plants and has approximately more than thousand species here in [1]. Several members in this genus are economic important crops providing edible fruit(e.g. tomato, *S. lycopersicum* L.; eggplant, *S.melongena* L.pepino, *S.muricastum* Ait.),edible tuber (potato, *S.tuberosum* L.), edible leaf and shoot as vegetable (coil-flowered nightshade, *S. spirale*Roxb.) and medicinally or ornamentally valuable (e.g. nightshades, *S. americanum* Mill., potato tree, *S.wrightii*Benth.) [2]. One of the causes in global warming problems claimed was aresult of overuses of land and fossil fuel for agriculture practices to increasing yield. After harvesting for edible parts (e.g. fruits, seeds, young shoot) of food crops or pruning ornamental plants, a huge amount of waste are left behind. Many researchers paid attention to utilize forest and agricultural residues as feedstock to substitutes the original raw materials such as softwood and hardwood for traditional forest products industries [3], [4].In order to reach that target, required properties as the pulp supplier of interesting plants must be investigated. Important criteria essential for pulp and paper industries are the fiber dimensions (i.e. fiber length, fiber diameter, fiber lumen diameter, and fiber cell wall thickness) and their derived indices such as slenderness ratio, Runkel ratio, and flexibility coefficient. These indices determine tearing strength of yielded paper and suitability of fiber raw materials [5], [6].

This study reported the characteristics of stem fiber of 15 species in the genus *Solanum* found in Thailand on the basis of examination via light microscopy.

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## II. Materials and Methods

### A. Plant Material

Stems or main branches of 15 species in the genus *Solanum*, S. *americanum* L., *S. capsicoides* All., *S. diphyllum* L., *S. lasiocarpum* Ortega, *S. lycopersicum* L., *S. mammosum* L.*, S. melongena* L.,*S. sanitwongsei*Craib, *S. seaforthianum*Andr., *S. spirale*Roxb., *S. torvum* Sw., *S. trilobatum* L., *S. violaceum* Ortega, *S. wrigthtii*Benth., and *S. tuberosum* L. obtained from all regions throughout Thailand were cut in June 2011. After being removed all leaves, its main axis from each species was divided into two pieces, the basal part(5 cm long) that was defined as stem base and the terminal one (the rest towards tip) which was defined as stem tip.

### B. Light Microscopy

To evaluate fiber micromorphological characteristics, stems or main branches were cut into 1 cm long manually under water. The samples were placed in glass bottles and boiled to remove cellular air-bubble. The absent air-bubble samples then were treated with 10% nitric acid and 10% chromic acid (1:1, v/v) overnight at room temperature for cell separation. These macerated colorless fibers were thoroughly washed with distilled water four times to remove acid prior to be stained for a week with 1% Safranin O. The stained fibers were dehydrated by passage through a graded ethanol series, cleared by incubation in xylene and Canada balsam (1:1, v/v) and then mounted in D.P.X. on to microscope slides. The morphological features of stem fibers of ≥ 30 cells per sample were inspected, measured (i.e. fiber length, fiber diameter, fiber cell lumen diameter and fiber cell wall thickness) and photographed using an OLYMPUS CH30 RF 300microscope (Olympus Optical, Tokyo, Japan).

### C. Statistical Analysis

To evaluate the statistical significant differences of fiber characteristics among species, the results were analyzed by Non parametric test at $P \leq 0.05$ using SPSS version 16.0 Software.

To assess the suitability of plant raw materials for paper production, comparisons among plant members of *Solanum*, softwood and hardwood on the three values derived from calculating of fiber dimensions: slenderness ratio as fiber length/fiber diameter, flexibility coefficient as (fiber lumen diameter/fiber diameter)x100 and Runkel ratio as (2 x fiber cell wall thickness)/lumen diameter [6], [7] were done.

## III. Results

### *A. Fiber Morphological Characteristics*

On the basis of fiber cell length measurement under the light microscope and position where that fiber belonged, 3 groups of plant were obtained. Firstly, the group with no significant differences in average fiber length between the two defined positions, included *S. diphyllum, S. mammosum, S. sanitwongsei, S. seaforthianum*, *S. torvum*, and the edible fruit species*, S. lycopersicum* which possessed the longest fiber of > 4 mm (Table I). Secondly, the group with longer fiber appeared in stem tip, in the range of 2.71- 4.89 mm were *S.americanum, S. melongena, S. spirale, S. trilobatum*, *and S. tuberosum*. Finally, the group with longer fiber presented in stem base in the range of2.91-4.27 mm, were *S. capsicoides, S. lasiocarpum, S. violaceum*, and *S. wrightii*. There were two groups of species classified from fiber cell diameter measurement, one with no significant differences in average diameter of fiber cells derived from that two positions (*S.americanum, S.lasiocarpum, S. lycopersicum, S. mammosum, S. spirale, S. torvum*, and *S. trilobatum*), whereas another with wider fiber cell diameter come from stem base. *S.lycopersicum* of the former has the widest fiber cell diameter>45.5 µm but of the later was from *S. wrightii* (46.6 µm) (Table I). Similarly to grouping by fiber length, average lumen diameter of fiber cell could be used to cluster species into 3 groups, *S. tuberosum* showed widest average fiber cell lumen diameter of approximately 27.84 µm in the group with no significant differences in average fiber cell lumen diameter between the two positions. *S. lycopersicum* fibers extracted from stem tippossess the widest average fiber cell lumen diameter of 35.68 µm. In the third group, the widest average fiber cell lumen (25.60 µm) obtained from fibers at stem base of *S. wrightii* (Table I). According to the thickness of fiber cell wall and fiber source positions, 3 groups of plant species were also clustered. The thickest wall was obtained from *S. wrightii* in the range of 9.68-10.24 µm in the first group, whereas were from *S.spirale* (7.32 µm) and *S. mammosum* (11.84µm) in the second and the third group respectively (Table I).

*Fiber indices of Solanum and possibly tend of stem fiber application as substitutes for forest produced wood*

According to the measurement of fiber dimensions and their derived indices in associate with positions where fibers were extracted, *S. americanum, S. lycopersicum, S. seaforthianum,* and *S. tuberosum* revealed higher fiber indices for fiber industrial applications in comparison with softwood and hardwood (Table II).

The slenderness ratio present in fibers extracted from stem tip and stem base of *S. americanum* and *S. tuberosum* were higher than those of the two comparing sources as 207.20, 125.00 and 163.93, 134.68 respectively. The slenderness ratio of fibers in stem base of *S. seaforthianum* (118.76) and *S. lycopersicum* (98.63)were higher than those from stemtipor of hardwood, but were approximately equal to that of softwood (95-120) (Table II).

On the basis of flexibility coefficient value, only the *S. Tuberosum* fibers either from stem tip (85.76) or stem base (84.51)were higher than that of softwood (75) and hardwood (55-70). On the other hand, *S. americanum, S. lycopersicum*, and *S. seaforthianum* fibers were approximately equal flexibility coefficient to that of hardwood but lower than that of softwood (Table II).

The lowest Runkel ratio presented in fibers extracted from both positions of stem were belonged to *S. tuberosum* (0.16, 0.16)and also lower than that of softwood (0.35) and hardwood (0.4-0.7) (Table II). The species with Runkel ratio ofapproximately equal to that of hardwood were*S. americanum* (0.48, 0.43), *S. lycopersicum* (0.34, 0.56), and *S. seaforthianum* (0.50, 0.51) (Table II).

## IV. Discussions

Fiber dimensions of 15 species in the genus *Solanum* reported in this study provided applicable data for taxonomic purpose. According to the length of fibers presented in three herbaceous species *S. lycopersicum*, *S. tuberosum* and *S. americanum*with no significant differences at P≤ 0.05 and were about in range of the longest fiber, these species seemed to have closely relationships. The relationship between *S. lycopersicum* and *S. tuberosum* was agreed their phylogeny inferred from chloroplast DNA sequence data [8]. Members of the genus with perennial habit and shrubby or tree appearance, (*S.capsicoides, S. diphyllum*, *S. lasiocarpum*, *S. mammosum*, *S. sanitwongsei*, *S. torvum*, *S. violaceum*, *S. wrightii*) mostly have longer fiber length at stem base. This might due to rapid growth of shoots occur in the early year. After main axis (stem) is established and start branching, to enhance the higher strength for supporting function, fiber cells may play roles by changing their cell structures with increasing cell wall thickness. In contrast, fibers found in new branches or stem tips possess relatively shorter cell and thinner wall (Table I) as the result of less requirement for supporting function and more physiological mechanism paying for flowers and fruits reproductions. However *S. trilobatum*, the spiny vine species needs high flexible ability of stem tip to twisting around the nearby plant or supporter. Therefore longer fiber cells with thinner wall were observed from stem tip, whereas ones with thicker cell wall that give rise to higher strength of stem were located at the stem base.

TABLE I
FIBER MORPHOLOGICAL CHARACTERISTICS AT TWO POSITIONS ON STEM OF 15 SPECIES OF *SOLANUM* FOUND IN THAILAND

| Species | Fiber length (mm) | | Fiber diameter (µm) | | Lumen diameter (µm) | | Fiber cell wall thickness(µm) | |
|---|---|---|---|---|---|---|---|---|
| | Stem tip | Stem base | Stem tip | Stem base | Stem tip | Stem base | Stem tip | Stem base |
| *S. americanum*L. | 4.89$^{Aa}$ | 2.69$^{CDb}$ | 23.60$^{Da}$ | 21.52$^{EFa}$ | 15.52$^{CDa}$ | 14.16$^{CDa}$ | 4.08$^{EFa}$ | 3.08$^{Gb}$ |
| *S.capsicoides*All. | 2.84$^{BCa}$ | 4.27$^{Ab}$ | 26.40$^{CDa}$ | 31.60$^{Bb}$ | 11.92$^{EFa}$ | 9.28$^{Eb}$ | 5.76$^{Da}$ | 9.64$^{Bb}$ |
| *S. diphyllum* L. | 2.50$^{BCa}$ | 2.54$^{Da}$ | 17.08$^{Fa}$ | 19.76$^{Fb}$ | 4.76$^{Ha}$ | 4.20$^{Fa}$ | 5.60$^{Da}$ | 6.76$^{DEb}$ |
| *S. lasiocarpum*Ortega | 1.61$^{Da}$ | 2.91$^{Cb}$ | 27.04$^{Ca}$ | 30.40$^{Ba}$ | 14.48$^{CDEa}$ | 15.84$^{CDa}$ | 6.08$^{CDa}$ | 7.64$^{CDa}$ |
| *S. lycopersicum*L. | 4.06$^{Aa}$ | 4.49$^{Aa}$ | 46.48$^{Aa}$ | 45.52$^{Aa}$ | 35.68$^{Aa}$ | 29.04$^{Ab}$ | 5.84$^{CDa}$ | 8.16$^{CDb}$ |
| *S. mammosum* L. | 2.87$^{Ba}$ | 3.20$^{BCa}$ | 32.76$^{Ba}$ | 33.32$^{Ba}$ | 14.28$^{CDEFa}$ | 6.08$^{Fb}$ | 6.88$^{BCa}$ | 11.84$^{Ab}$ |
| *S. melongena* L. | 2.93$^{Ba}$ | 2.11$^{Eb}$ | 21.60$^{Ea}$ | 26.36$^{CDb}$ | 10.20$^{Fa}$ | 13.20$^{Db}$ | 5.28$^{Da}$ | 6.08$^{Ea}$ |
| *S. sanitwongsei*Craib | 2.30$^{Ca}$ | 2.33$^{DEa}$ | 23.48$^{Da}$ | 28.52$^{Cb}$ | 4.00$^{Ha}$ | 6.56$^{Fb}$ | 8.60$^{Aa}$ | 9.08$^{BCa}$ |
| *S. seaforthianum*Andr. | 2.79$^{BCa}$ | 3.43$^{BCa}$ | 23.96$^{Da}$ | 28.88$^{BCb}$ | 15.72$^{CDa}$ | 18.68$^{BCa}$ | 3.72$^{Fa}$ | 4.84$^{Fb}$ |
| *S. spirale*Roxb. | 2.71$^{BCa}$ | 2.17$^{DEb}$ | 21.76$^{Ea}$ | 19.48$^{Fa}$ | 6.80$^{Ga}$ | 7.68$^{EFa}$ | 7.32$^{Ba}$ | 5.76$^{Eb}$ |
| *S. torvum* Sw. | 2.48$^{BCa}$ | 2.89$^{Ca}$ | 25.76$^{CDa}$ | 26.68$^{CDa}$ | 15.40$^{CDa}$ | 14.16$^{CDa}$ | 4.88$^{DEa}$ | 6.36$^{Eb}$ |
| *S. trilobatum* L. | 4.10$^{Aa}$ | 3.23$^{BCb}$ | 24.48$^{CDa}$ | 24.12$^{DEa}$ | 17.04$^{Ca}$ | 9.32$^{Eb}$ | 3.44$^{Fa}$ | 7.32$^{Db}$ |
| *S. tuberosum*L. | 4.80$^{Aa}$ | 3.93$^{ABb}$ | 29.28$^{Ca}$ | 35.64$^{Bb}$ | 25.56$^{Ba}$ | 30.12$^{Aa}$ | 1.88$^{Ga}$ | 2.52$^{Gb}$ |
| *S. violaceum* Ortega | 1.65$^{Da}$ | 3.48$^{BCb}$ | 24.08$^{CDa}$ | 28.40$^{Cb}$ | 12.12$^{EFa}$ | 8.12$^{EFb}$ | 5.80$^{Da}$ | 10.00$^{Bb}$ |
| *S. wrightii*Benth. | 2.31$^{Ca}$ | 3.20$^{BCb}$ | 33.00$^{Ba}$ | 46.60$^{Ab}$ | 13.84$^{DEa}$ | 25.60$^{Ab}$ | 9.68$^{Aa}$ | 10.24$^{ABa}$ |

[1]Meansfollowed by the same capital letters within the same column are not significantly different at *P ≤ 0.05* by Non parametric test and means followed by the same small letters within the same row are not significantly different at P ≤ 0.05 by Non parametric test.

TABLE II
STEM FIBER DERIVED INDICES OF TWO POSITIONS ON STEM OF 15 SPECIES OF *SOLANUM* FOUND IN THAILAND

| Species | Slenderness ratio | | Flexibility coefficient | | Runkel ratio | |
|---|---|---|---|---|---|---|
| | Stem tip | Stem base | Stem tip | Stem base | Stem tip | Stem base |
| *S. americanum*L. | 207.20 | 125.00 | 65.78 | 65.79 | 0.48 | 0.43 |
| *S.capsicoides*All. | 107.57 | 135.12 | 36.55 | 29.36 | 1.17 | 2.07 |
| *S. diphyllum* L. | 146.37 | 128.54 | 24.32 | 21.25 | 0.82 | 3.21 |
| *S. lasiocarpum*Ortega | 59.54 | 95.72 | 52.79 | 52.10 | 0.91 | 0.96 |
| *S. lycopersicum*L. | 87.34 | 98.63 | 70.35 | 63.79 | 0.34 | 0.56 |
| *S. mammosum* L. | 87.60 | 96.03 | 30.81 | 18.24 | 0.79 | 3.89 |
| *S. melongena* L. | 135.64 | 80.04 | 48.79 | 50.07 | 0.97 | 0.92 |
| *S. sanitwongsei*Craib | 97.95 | 81.69 | 20.38 | 23.00 | 3.34 | 2.76 |
| *S. seaforthianum*Andr. | 116.44 | 118.76 | 65.10 | 64.68 | 0.50 | 0.51 |
| *S. spirale*Roxb. | 124.54 | 111.39 | 35.11 | 39.42 | 1.81 | 1.50 |
| *S. torvum* Sw. | 96.27 | 108.32 | 56.37 | 53.07 | 0.76 | 0.89 |
| *S. trilobatum* L. | 167.48 | 133.91 | 54.15 | 38.64 | 0.81 | 1.57 |
| *S. tuberosum*L. | 163.93 | 134.68 | 85.76 | 84.51 | 0.16 | 0.16 |
| *S. violaceum* Ortega | 68.52 | 122.53 | 58.29 | 28.59 | 1.56 | 2.46 |
| *S. wrightii*Benth. | 70.00 | 68.66 | 49.55 | 54.93 | 1.01 | 0.80 |
| Softwood [7] | 95-120 | | 75 | | 0.35 | |
| Hardwood [7] | 55-75 | | 55-70 | | 0.4-0.7 | |

Under light microscope examination, fibers extracted from herbaceous *Solanum* species tended to provide qualified fundamental properties of raw material fibers used in pulping and papermaking, i.e. fibers with long length, high slenderness ratio (>33), high flexibility coefficient (>60), and low Runkel ratio (<1) in comparison to those of softwood and hardwood. Two food crops species, *S. lycopersicum* and *S. tuberosum* retained relatively long length fibers with the mean length without position considering of >3.9 mm whereas that of weedy species, *S. americanum* and ornamental species, *S. seaforthianum* were>2.6 mm. The former two species have wide lumina, with diameter from 25.56 µm to 35.68 µm whereas from 14.16 µm to18.68 µm in the two later ones.

The slenderness ratio present in *S. americanum* and *S. tuberosum* fibers either from stem tip or stem base are higher than of softwood and hardwood whereas only extracted fibers from stem base of *S. seaforthianum* and *S. lycopersicum* have higher value than that of hardwood, and approximately equal to that of softwood. This higher value implied to leading trend to increase the tearing resistance property of those species fibers[7].Among 15 *Solanum* species studied herein *S. tuberosum* fibers have the highest flexibility coefficient and are higher than that of hardwood (55-70) and softwood (75), yield pulps with acceptable breaking range, tear and burst indices suitable for newsprint paper production [3]. Moreover, Runkel ratio of *S. tuberosum* fiber is the lowest and lower than that of softwood and hardwood. This makes the species ability to enhance the mechanical strength during pulping [9]. *S. americanum, S. lycopersicum*, and *S. seaforthianum* fibers are still in group with acceptable property for feedstock in paper production on the basis of higher flexibility coefficient and lower Runkel ratio. However they are inferior under *S. tuberosum* as the result of limited location sources of fibers. To improve paper strength in papermaking, increasing flexibility coefficient of >60 was reported necessary [10], [11]. In order to produce good surface contact as well as fiber-to-fiber bonding, input fibers with high flexibility coefficient are always considered at the first priority [3]. The most favorably practice was mixing tentative new pulps with softwood, hardwood of recycled paper pulps to increase mechanical strength or be used to partially replace hardwood pulps in various paper grades but still in relatively low ratios for its poor slenderness [3].

## V. Conclusions

Microstructural characteristic of stem fibers provided useful data to grouping 15 species member of *Solanum* found in Thailand. The fiber dimensions and their derived indices reported herein show that *S.americanum* L.,*S. lycopersicum*, *S. seaforthianum* Andr., and *S. tuberosum* L. tend to be a subsidiary material or a potential substitute for hardwood and softwood in traditional forest product industries

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