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Cuticle Micromorphology of Korean Gymnosperms I. Cycadaceae, Ginkgoaceae, Taxaceae and Cephalotaxaceae

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Cuticle micromorphology of four families of Korean gymnosperms, Cycadaceae, Ginkgoaceae, Taxaceae, and Cephalotaxaceae, were studied with scanning electron microscopy. The outer and inner features of abaxial and adaxial cuticles were described in details; the absent or present of Florin ring, orifice, trichome, and plug and their shape, the shape and periclinal and anticlinal wall sculpture of epidermal cells, the shape of cuticular flange of epidermal cell, guard cell, and subsidiary cell, the number of stomatal bands and rows, and stomatal apparatus including the shape of polar extension, number of subsidiary cells, the sculpture of guard cell and subsidiary cell. Most of these features have not been sufficiently substantiated by the previous reports. Furthermore, all the species investigated showed distinctive cuticle morphology with morphological and taxonomical informations.

Keywords: cuticle, Korean gymnosperms (*Cycas, Ginkgo, Torreya, Taxus, Cephalotaxus*)

The gymnosperms have a long evolutionary history extending back to at least 300 milion years (Miller, 1977, 1988). There are 70 extant genera with approximately 760 species in the world (Mabbery, 1990). The gymnosperms are widespread in the Northern and Southern hemisphere and become the major constituents of forests in both the hemispheres. In addition, most of them are of great economic importance as sources of lumber, wood pulp and road side trees, etc. In Korea, approximately 40 species of gymnosperms belonging to 21 genera and 8 families are distributed (Lee, 1982).

Much paleobotanical attention has been given the gymnosperms (*e.g.* Gifford and Foster, 1989; Stewart and Rothwell, 1993). Since sterile foliage is often all that is available of gymnospermous material, a knowledge of leaf morphology is essential for identification and understanding of their interrelationships. Therefore investigation of the morphology of gymnosperm leaves have been performed (*e.g.* Florin, 1931; Chamberlain, 1935; Laubenfels, 1953). At the beginning of this century, paleobotanists have examined preserved fossil cuticle from the soil in order to characterize the taxa (Edwards *et al.*, 1982). In addition, increasing attention has been paid to the systematic study of the cuticle and epidermis in living gymnosperms (Florin, 1931). Moreover, many works of cuticle micromorphology have been stimulated by employing the scanning electron microscope (Oladele, 1981a, b; Alvin *et al.*, 1982; Stockey and Ko, 1986, 1988; Hill and Carpenter, 1991; Hill and Pole, 1992; Stockey and Atkinson, 1993). These studies have proved that cuticle micromorphology is very much valuable for the studies on paleobotany and plant systematics.

In order to appreciate the morphology of the fossilized leaves, it is necessary to investigate the cuticle micromorphology of the living gymnosperm leaves as reference materials. However, most previous works which include cuticle micromorphology of the gymnosperms involved limited taxa or confined to specific regions of the world.

This research is done to investigate the cuticle micromorphology of five species of Korean gymnosperm. This objective is obviously too broad to be

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treated in a single article. This paper, however, deals with only four families of Korean gymnosperms, Cycadaceae, Ginkgoaceae, Taxaceae, and Cephalotaxaceae. The other groups will be investigated in future studies.

MATERIALS AND METHODS

Living specimens of *Cycas revoluta* Thunb., *Ginkgo biloba* L., *Torreya nucifera* Sieb. et Zucc., *Taxus cuspidata* Sieb. et Zucc., and *Cephalotaxus koreana* Nakai were readily available at the Chonbuk National University. All the species were collected in the end of 1994 and the early of 1995. Cuticles were prepared by soaking leaf fragments in 5% aqueous chromium trioxide until all organic matter except the cuticle was dissolved. Some cuticles were mounted on aluminium stubs with double sided adhesive tape and air dried. The stubs were then the sputter coated with pure gold to a maximum thickness of 15 nm, and examined with a ISI ABT (SR-50) scanning electron microscope operated at 10 kV. The remaining cuticles were neutralized in 5% ammonia, stained with 1% safranin O, and mounted on microscope slides in Canada balsam.

RESULTS

Cuticle micromorphology of five taxa investigated is as follows and the characteristics of leaf morphology, outer and inner cuticular surface, are summarized in Table 1, 2, and 3.

Cycas revoluta Thunb.

Adult pinnae are spreading being linear, alternately arranged, and homofacially flattened. They are in the range of 4-20 cm long and 0.5-0.8 cm wide with attenuate top. The petioles are absent. Stomates distribute over the entire area in two broad bands on the abaxial surface of pinnae except for margin and robust mid-vein (Table 1).

The outer cuticular surface (Table 2): Adaxial side is slightly undulating with epidermal cell outlines visible and abaxial side is relatively smooth (Figs. 1, 2). Papillae are not developed. Florin rings are virtually absent, at the stomatal orifice being surrounded by slightly raised area (Figs. 1, 2). Stomatal orifices are variable, being circular to elliptical (Fig. 1). Stomatal plugs are absent. Stomates are randomly scattered (Figs. 1, 4). There are many round hair bases on abaxial side surrounded by irregularily raised areas (Fig. 3).

The inner cuticlar surface (Table 3): Stomatal orientation is random (Fig. 4). There are about ten subsidiary cells per stomatal complex (Fig. 5). The subsidiary cells join at their external margins to give the stomatal apparatus an oval shape with several

Table 1. Leaf morphology of five gymnosperm species in Korea

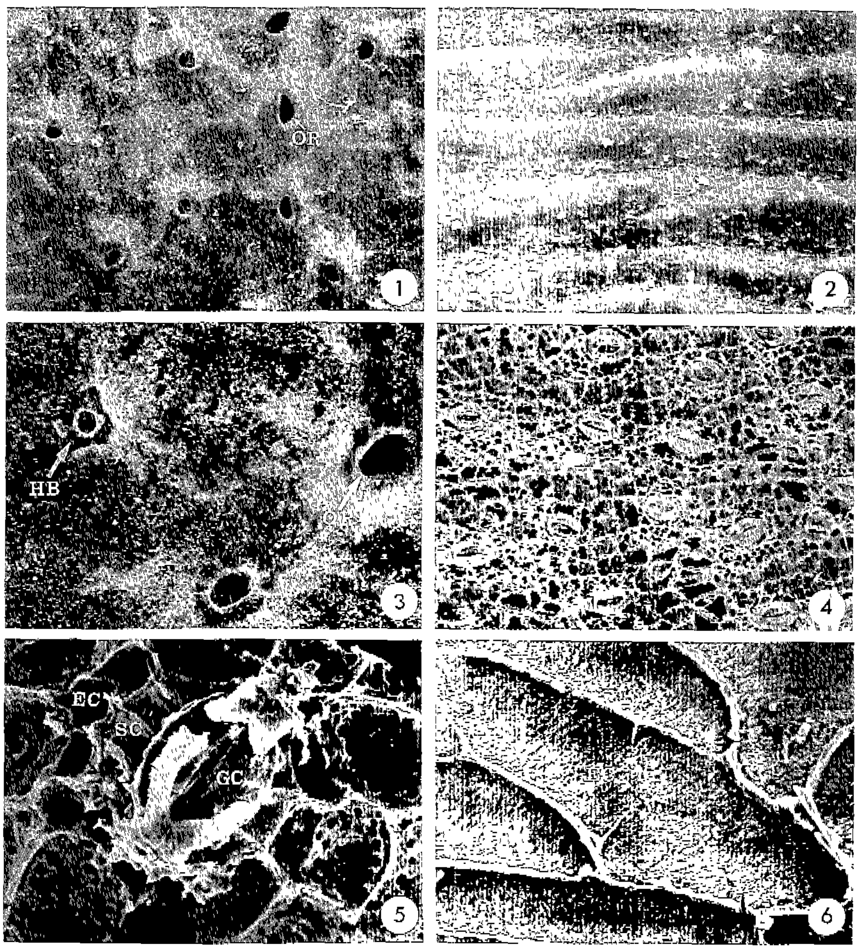
Species / Characters	*Cycas revoluta*[b]	*Ginkgo biloba*	*Torreya nucifera*	*Taxus cuspidata*	*Cephalotaxus koreana*
Shape	linear	flabellate	linear	linear to falcate	linear to slightly falcate
Dimension L×W (cm)[a]	4.0-20.0×0.5-0.8	3.0-6.0×3.0-10.0	1.5-2.5×0.2-0.3	1.5-3.0×0.2-0.3	2.0-4.0×0.2-0.4
Arrangement	alternate	alternate	spiral	spiral	spiral
Base	–	decurrently acute	cuneately acute	cuneatly acute	cuneatly obtuse
Top	attenuate	deeply notched	acuminate	acuminate	acuminate
No. of vein	one	numerous	one	one	one
Stomatal distribution	hypostomatic	hypostomatic, rarely unequal amphistomatic	hypostomatic	hypostomatic	hypostomatic
Stomatal band	two, broad	numerous, broad	two, narrow	two, moderately broad	two, broad
Petiole (cm)	absent	present (1.5-6.0)	present, twisted (0.1-0.3)	present, twisted (0.1-0.2)	rudiment, twisted

[a]L, length; W, width. [b]Morphology of one pinna.

Table 2. Outer cuticular features on leaves of five gymnosperm species in Korea

Species / Characters	*Cycas revoluta*	*Ginkgo biloba*	*Torreya nucifera*	*Taxus cuspidata*	*Cephalotaxus koreana*
Surface	slightly undulate (Ad), smooth (Ab)	irregularly undulate (Ab, Ad)	undulate (Ab, Ad)	undulate (Ab), smooth (Ad)	undulate (Ab, Ad)[a]
Florin ring	absent	present, lobed & interrupted	unknown	present, lobed & interrupted	absent
Ridge	low	low	unknown	high	absent
Groove	absent	absent	unknown	present	absent
Trichome	hair type	papillae, variable	papillae, clump	papillae, variable	absent
Stomatal plug	absent	absent	absent	absent	present
Stomatal orifice	mostly circular to elliptical	irregular	unknown	various, mostly rectangular	elliptical

[a]Ad and Ab, Adaxial and abaxial sides of leaf.



Figs. 1-6. Scanning electron micrographs of the cuticular micromorphology of *Cycas revoluta* Thunb. Fig. 1. Outer view, abaxial side, showing the various shape of orifice and the absence of Florin ring. ×240. Fig. 2. Outer view, adaxial side, showing slightly undulating surface. ×800. Fig. 3. Outer view, abaxial side, showing a hair base. ×540. Fig. 4. Inner view, abaxial side. Note the random orientations of stomates. ×220. Fig. 5. Inner view, abaxial side, showing the subsidiary and guard cells surrounded by epidermal cells. ×830. Fig. 6. Inner view of the epidermal cells of abaxial side. ×1,100. **Abbreviation:** EC, epidermal cell; FR, Florin ring; GC, guard cell; GR, groove; HB, hair base; HC, hypoplastic cell; LS, lateral subsidiary cell; OR, orifice; PA, papillae; PC, polar subsidiary cell; PE, polar extension; SC, subsidiary cell; SP, stomatal plug; SR, stomatal row.

ridges (Fig. 5). Cuticle on subsidiary cells shows granular and pitted surface (Fig. 5). There is no pronounced groove near guard cells (Fig. 5).

The cuticular flange between guard cells and subsidiary cells is thick and smooth (Fig. 5). The cuticular flange between guard cells is not developed (Fig. 5). Polar extensions are broad, thick, and well developed so that they often unite with the flange of guard cells and subsidiary cells (Fig. 5). Cuticle on the guard cell surface is smooth and finely pitted (Fig. 5).

Epidermal cells are irregular in shape (Fig. 6). But those near the stomates are especially smaller than the others (Fig. 5). The anticlinal wall of epidermal cells is serrate and often has an interrupted outer flange (Fig. 6). Periclinal wall of epidermal cells on adaxial side is pitted without tubercles and that on adaxial side is porous (Figs. 5, 6).

Ginkgo biloba L.

Adult leaves are spreading being flabelliform with bilobed or entire margin, alternately or fasciculately arranged on short spurs, and the blades are flattened. They are in the range of 3-6 cm long and 3-10 cm wide with deeply notched top and deccurrently acute base, and usually have a long petiole in 1.5-6 cm long. Stomates are restricted to areas as numerous broad bands between the veins on abaxial leaf surface (Table 1). In particular male plant leaves usually have a few stomata on the adaxial side. Mid-vein is absent and numorous fine veins show dichotomous venation.

The outer cuticular surface (Table 2): Within the stomatal region, the surface is irregularly undulating, revealing underlying epidermal cell outlines (Fig. 7). But that on the vein shows more or less regular undulations with epidermal cell outlines clearly visible (Fig. 9). There are many papillae in stomatal region and their shapes are various; circular, rectangular and elliptical. Florin rings are moderately developed which are lobed and interrupted (Figs. 7, 8). Stomatal plugs are absent (Figs. 7, 8). Stomatal orifices are irregular in shape and size (Fig. 7). Stomates are randomly scattered (Figs. 7, 10).

The inner cuticular surface (Table 3): Subsidiary cells are not distinct, but it could be suggested on the basis of outer surface view that there may be four or five subsidiary cells in each stomatal complex (Figs. 10-12). Stomatal orientation is irregular. The shape of stomates is various, being oval to elliptical with polar extensions (Figs. 11, 12). There is no groove near the guard cells (Figs. 10, 12).

The cuticular flange of external margin of guard cells and between them is thick and smooth (Figs. 11, 12). The cuticular flange of epidermal cells on the vein is smooth and thick. Polar extensions are relatively broad and thick with weak ridge (Fig. 11). Cuticle on the guard cell surface is smooth near stomatal pore and granulate near the margin (Fig. 11).

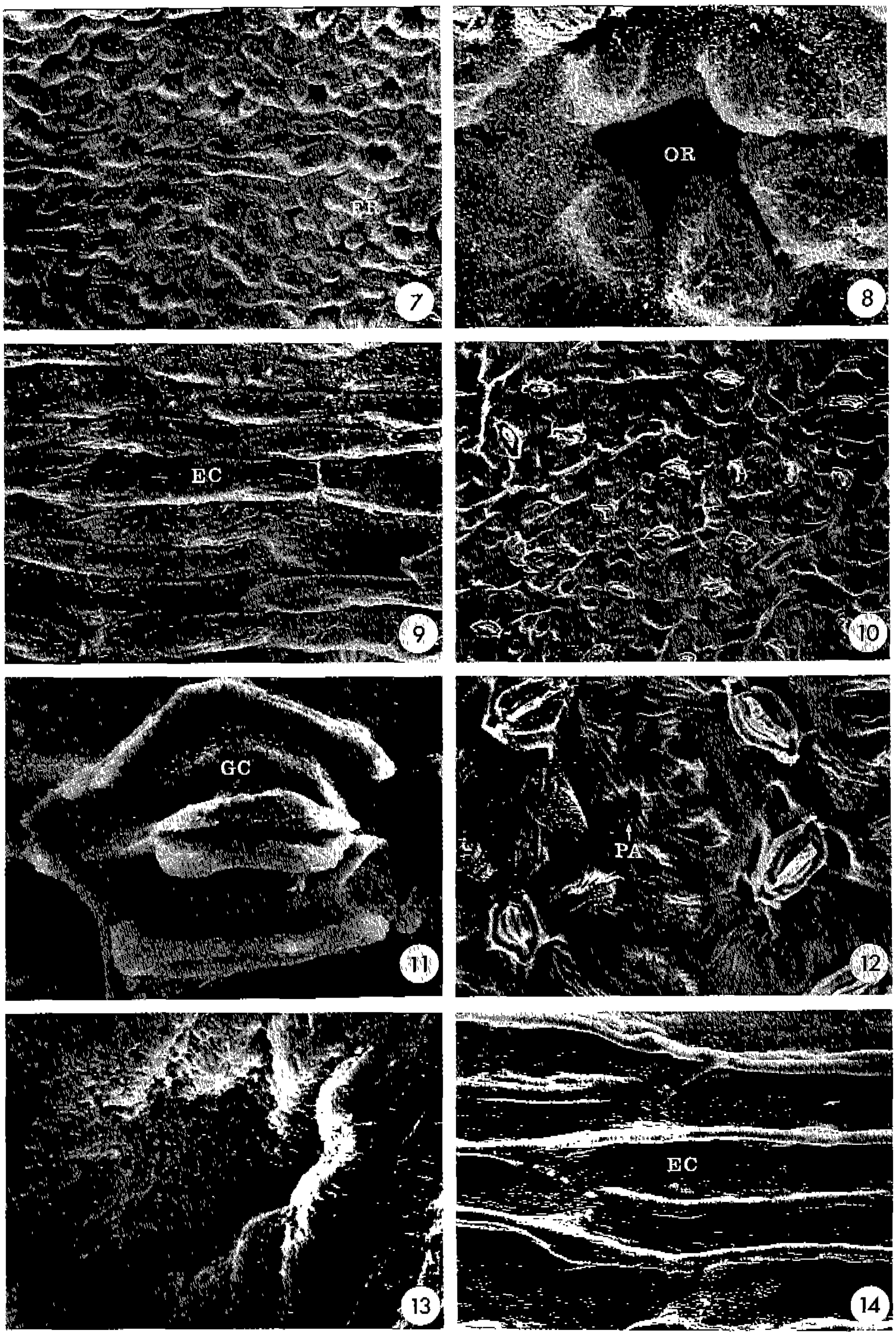
The outlines of epidermal cells within stomatal region are not distinct (Figs. 10, 12). Periclinal wall of epidermal cells can be distinguished into three areas; smooth, granulate, and striate. But the inside of papillae is always granulate (Figs. 12, 13). The periclinal wall of the epidermal cells on the vein is finely granulated (Fig. 14).

Torreya nucifera Sieb. et Zucc.

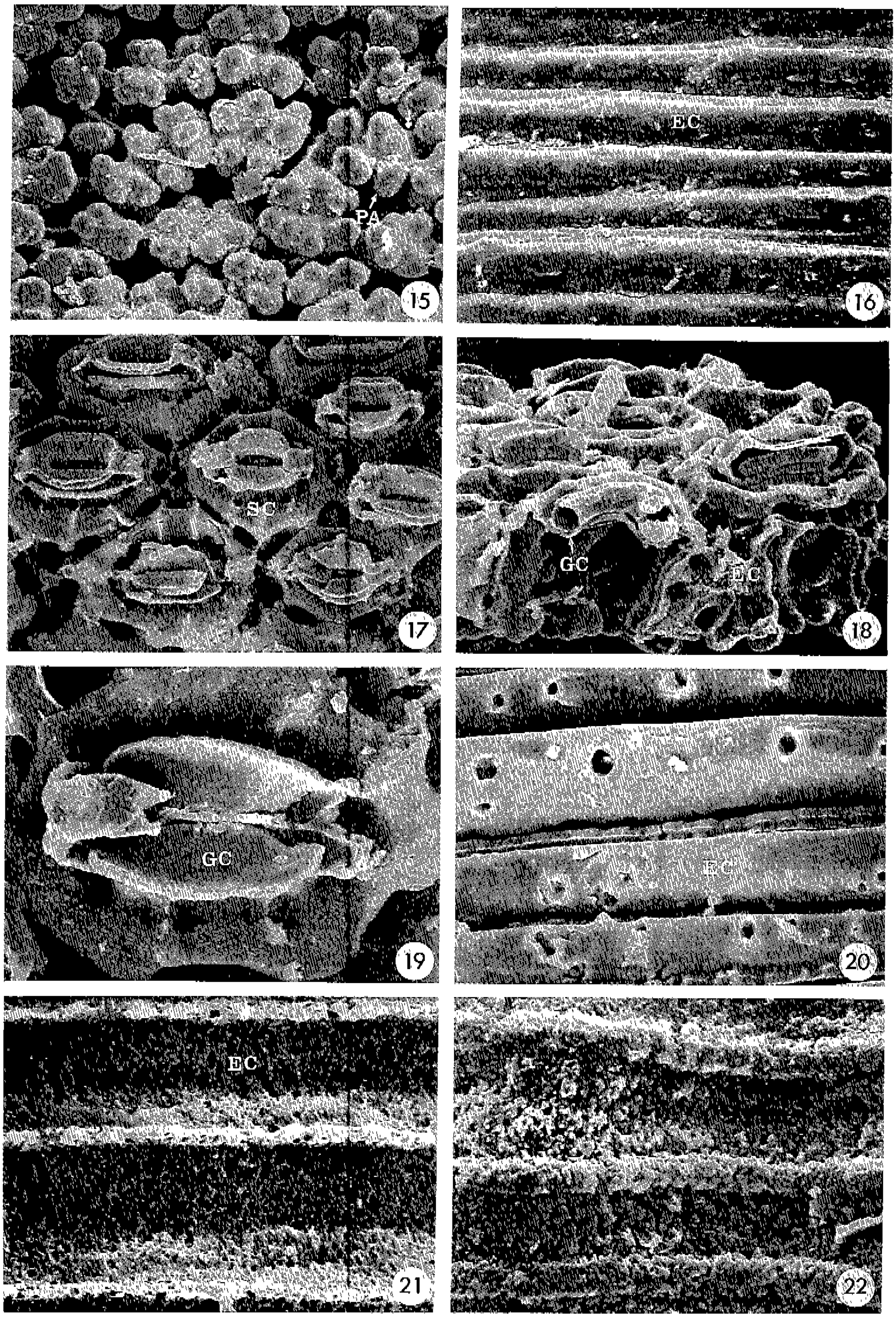
Adult leaves are spreading being linear and keeled, spirally arranged appearing 2-ranked and homofacially flattened. They are in the range of 1.5-2.5 cm long and 0.2-0.3 cm wide with acuminate top and cuneately acute base and have a twisted petiole in 0.1-0.3 cm long. Stomates are in two narrow bands on either side of the robust mid-vein, and run for the entire length on abaxial leaf surface (Table 1).

The outer cuticular surface (Table 2): Both sides of leaves except for stomatal area, are undulating with epidermal cell outlines visible (Fig. 16). Within stomatal band, there are many distinctive papillae clumps (Fig. 15). Florin rings, stomatal orifices, and stomatal plugs are undefinable due to sunken stomates below papillae clumps (Fig. 15).

The inner cuticular surface (Table 3): Stomatal rows are continuous, and stomates are alternatively arranged between adjacent rows (Fig. 17). The number of stomatal rows within a stomatal band ranges six to eight. The stomatal rows are often separated by one layer of epidermal cells. Within stomatal rows, stomates are separated by one or two epidermal cells so that polar subsidiary cells are not shared with neighbour stomates (Fig. 17). The shape of epidermal cells within the stomatal rows is undefinable



Figs. 7-14. Scanning electron micrographs of the cuticular micromorphology of *Ginkgo biloba* L. Fig. 7. Outer view, abaxial side. Note the slightly and irregularly undulating surface, and Florin rings. ×245. Fig. 8. Higher magnification of Florin ring and stomatal orifice in Fig. 7. Note the interrupted Florin ring. ×1,520. Fig. 9. Outer view, adaxial side. Note the undulating surface with epidermal cell outline visible. ×640. Fig. 10. Inner view, abaxial side, showing randomly oriented stomates. ×195. Fig. 11. Higher magnification of stomates in Fig. 10, showing guard cells and their flanges. ×3,250. Fig. 12. Inner view, adaxial side, showing smooth and granular periclinal wall of epidermal cells. Note the papillae. ×600. Fig. 13. Higher magnification of papillae in Fig. 12, showing the granular inside and furrow around papillae. ×3,200. Fig. 14. Inner view, adaxial side, showing periclinal and anticlinal cell wall over the vein. ×950.



Figs. 15-22. Scanning electron micrographs of the cuticular micromorphology of *Torreya nucifera* Sieb. et Zucc. Fig. 15. Outer view, abaxial side, showing papillae clumps. ×560. Fig. 16. Outer view, adaxial side. Note the undulating surface with epidermal cell outline visible. ×960. Fig. 17. Inner view, abaxial side. Note the alternate arrangement of stomatal rows. ×450. Fig. 18. Cross section of leaf, showing the outline of epidermal cells including papillae, guard cells covered with cuticle, and boundary between subsidiary cells and epidermal cells. ×550. Fig. 19. Inner view of stomatal apparatus. ×1,280. Fig. 20. Inner view, abaxial side. Note the covering of epidermal cells by cuticles. ×2,500. Fig. 21. Inner veiw, abaxial side, showing the long epidermal cells and their wall pattern. ×2,800. Fig. 22. Inner view, adaxial side, showing the long epidermal cells and their wall pattern. ×2,100.

Table 3. Inner cuticular features on leaves of five gymnosperm species in Korea

Characters \ Species	*Cycas revoluta*	*Ginkgo biloba*	*Torreya nucifera*	*Taxus cuspidata*	*Cephalotaxus koreana*
Epidermal cell	irregular	irregular	long rod with oblique end wall to irregular	short rectangular with vertical end wall	moderately short rectangular
Periclinal wall	pitted	smooth, granular, striate	porous & granular	granular with tubercles	pitted & granular
Anticlinal wall	serrate	obscure	straight with pitted	straight	straight
GC[a] surface	smooth	pitted	smooth	smooth	smooth
SC[b] surface	granular & pitted	granular	slightly pitted	granular & pitted	finely pitted
Stomatal orientation to long axis	random	random	parallel	parallel	parallel
Stomatal apparatus	oval	variable	oval	oval, polar cells project	oval, polar cells project
Polar extension	broad & thick	broad & thick	narrow & thick	broad & thin	narrow & thick
No. of SC	ca. 10	4-5 (?)	8-10	4-6	4 rarely 5
Groove near GC	absent	absent	present	present	absent
Stomatal row	scatterted	scattered	continuous, alternate	continuous	continuous
No. in band	–	–	6-8	12-9	15-20
Cuticular flange between GCs	undeveloped	thick & smooth	thick & smooth almost covering the guard cell	thick & smooth	thin, covering the guard cell
Cuticular flange between GC and SC	thick & smooth	thick & smooth	thick & smooth	thick & smooth	thin, covering the guard cell

[a]GC, guard cell; [b]SC, subsidiary cell.

due to burying below stomatal apparatus (Figs. 15, 17). Stomatal orientation aligns parallel to the long axis of leaf (Fig. 17). There are eight to ten subsidiary cells in each stomatal apparatus by dividing both the lateral subsidiary cells and polar subsidiary cells (Figs. 17, 19). The subsidiary cells join at their external margins to give the stomatal apparatus an oval shape with several ridges (Figs. 17, 19). There is pronounced groove near guard cells (Fig. 17). Cuticle on subsidiary cells is thick (Figs. 17-19).

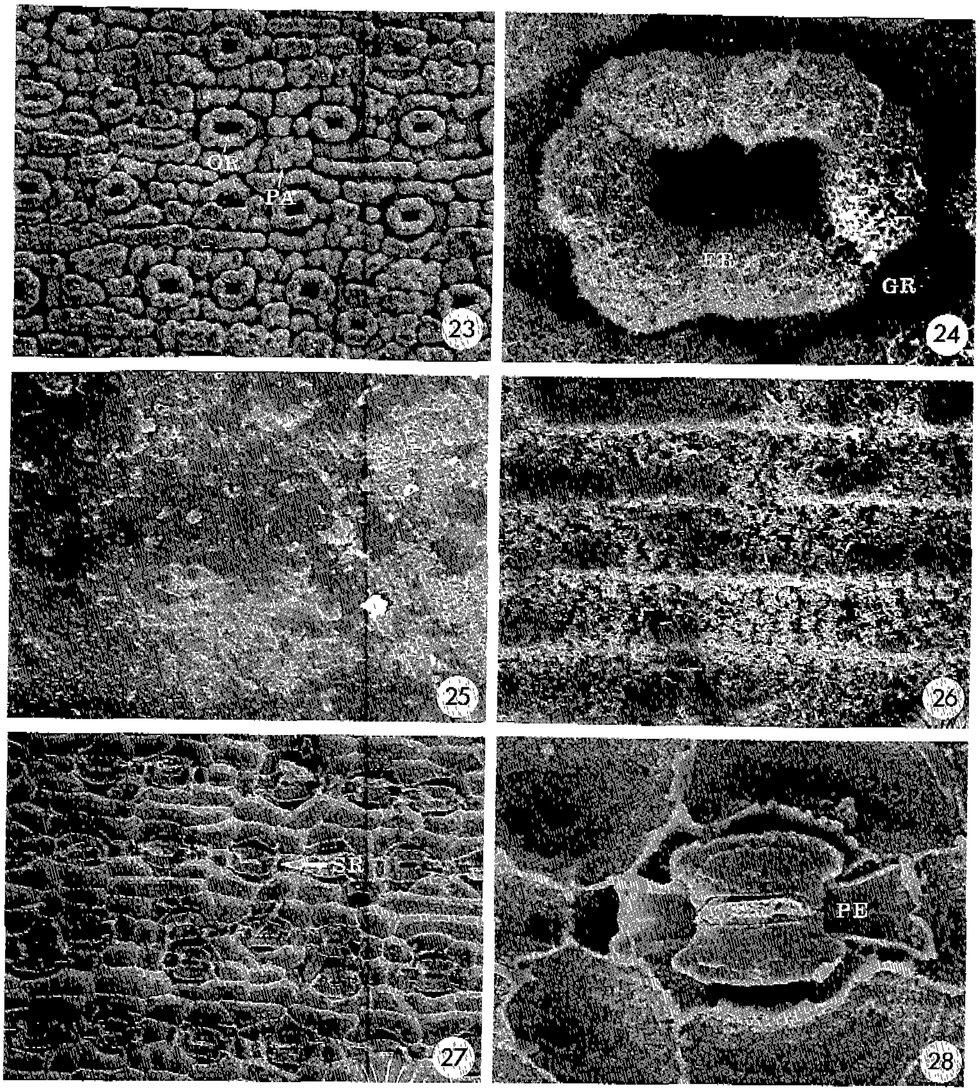
The cuticular flange between subsidiary cells and epidermal cells is not developed (Fig. 17). The cuticular flange, both, between guard cells and lateral subsidiary cells, and between guard cells is well developed so that guard cells are almost covered with cuticular flange (Figs. 17, 18). Polar extensions are narrow and thick, and well developed so that they unite with the flange of guard cells (Figs. 17, 18). Cuticles on the surface of guard cells and subsidiary cells are smooth and finely pitted respectively (Fig. 19).

Epidermal cells in stomatal free regions are long rod-shape with oblique end wall (Figs. 20-22). The anticlinal wall of epidermal cells is straight and pitted, and that on the abaxial side is thicker than that on the adaxial side (Figs. 21, 22). Periclinal wall of epidermal cells shows somewhat a mixture of porous and granular surface without tubercles (Figs. 21, 22).

Taxus cuspidata Sieb. et Zucc.

Adult leaves are spreading being linear to sometimes falcate, spirally arranged appearing 2-ranked and homofacially flattened. They are in the range of 1.5-3 cm long and 0.2-0.3 cm wide with acuminate top and cuneately acute base, and have a twisted petiole in 0.1-0.2 cm long. Stomates are in two moderately broad bands on either side of the robust mid-vein, and run for the entire length on abaxial leaf surface (Table 1).

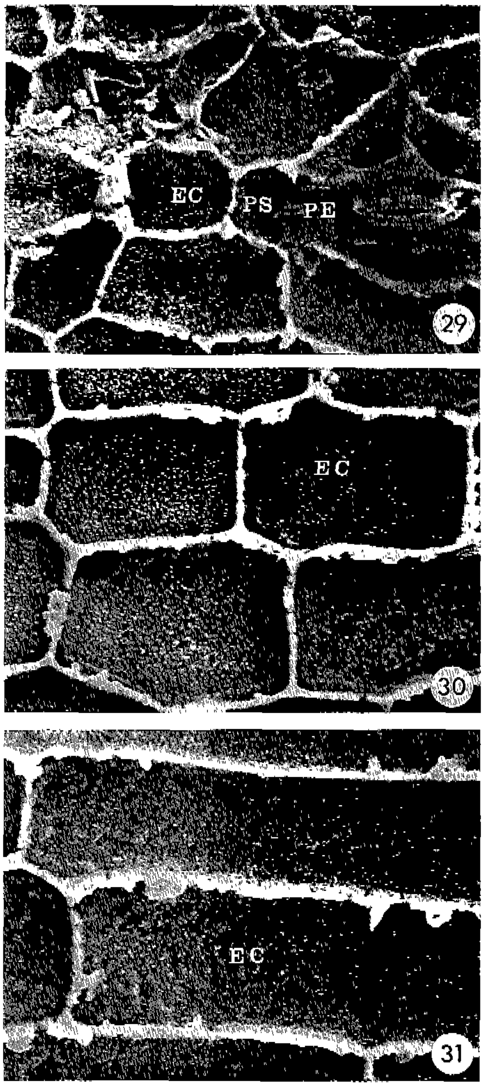
The outer cuticular surface (Table 2) : Adaxial side is smooth, being no distinctive feature, but that of abaxial side is undulating with epidermal cell outlines visible in part (Figs. 25, 26). Within stomatal



Figs. 23-28. Scanning electron micrographs of the cuticular micromorphology of *Taxus cuspidata* Sieb. et Zucc. Fig. 23. Outer view, abaxial side. Note the various papillae and Florin rings. ×280. Fig. 24. Higher magnification of Florin ring surrounded by groove. ×1,900. Fig. 25. Outer view, adaxial side, showing smooth surface. ×1,450. Fig. 26. Outer view, abaxial side, showing undulating surface. ×960. Fig. 27. Inner view, abaxial side, showing the parallel arrangements of stomates. ×260. Fig. 28. Higher magnification of stomatal apparatus in Fig. 27. Note the thick and wide polar extension. ×1,300.

band, many papillae are developed and their shape are various being circular, elliptical, and multi-lobed rod etc. (Fig. 23). Florin rings are prominent with a high ridge, lobed, and interrupted, and also surrounded by groove (Figs. 23, 24). Stomatal plugs are absent (Fig. 23). Stomatal orifices are commonly rectangular but show a variable shape and size (Fig. 23).

The inner cuticular surface (Table 3): Stomatal rows are mostly continuous (Fig. 27). The number of stomatal rows within a stomatal band ranges nine to eleven. The stomatal rows are often separated by one to three rows of epidermal cells (Fig. 27). Within stomatal rows, stomates are separated by three or fewer epidermal cells (Fig. 27). These cells are usually shorter than epidermal cells between stomatal rows. Stomatal orientation aligns parallel to the long leaf axis (Fig. 27). The number of subsidiary cells is typically four with two polar and two lateral subsidiary cells. But there are also five to six subsidiary cells by the division of often one or rarely both of the lateral subsidiary cells. Stomatal apparatus is



Figs. 29-31. Scanning electron micrographs of the cuticular micromorphology of *Taxus cuspidata* Sieb. et Zucc. Fig. 29. Inner view of polar subsidiary cell and adjacent epidermal cells. ×1,150. Fig. 30. Inner view, abaxial side, showing the wall pattern of epidermal cells. ×1,150. Fig. 31. Inner view, adaxial side, showing the shape and periclinal wall pattern of epidermal cells. ×1,350.

oval; however, the polar subsidiary cells usually project beyond a continuation of the external margins of the lateral subsidiary cells so that the stomatal apparatus does not have a smooth oval outline (Figs. 27, 28). Cuticle on subsidiary cells is thicker and more granular than that on epidermal cells (Figs. 28, 29), and forms pronounced groove near guard cells (Figs. 28, 29).

The cuticular flange between subsidiary cells and epidermal cells is irreguair by the extension of cuticle toward the hypodermal level (Fig. 29). The cuticular flange, both, between guard cells and lateral subsidiary cells, and between guard cells is nearly smooth with small serration at the edge (Figs. 28, 29). Polar extensions are relatively broad with ridge and irregular edge and extend out over the polar subsidiary cells (Figs. 28, 29). Cuticle on the guard cell surface is smooth with small number of pores.

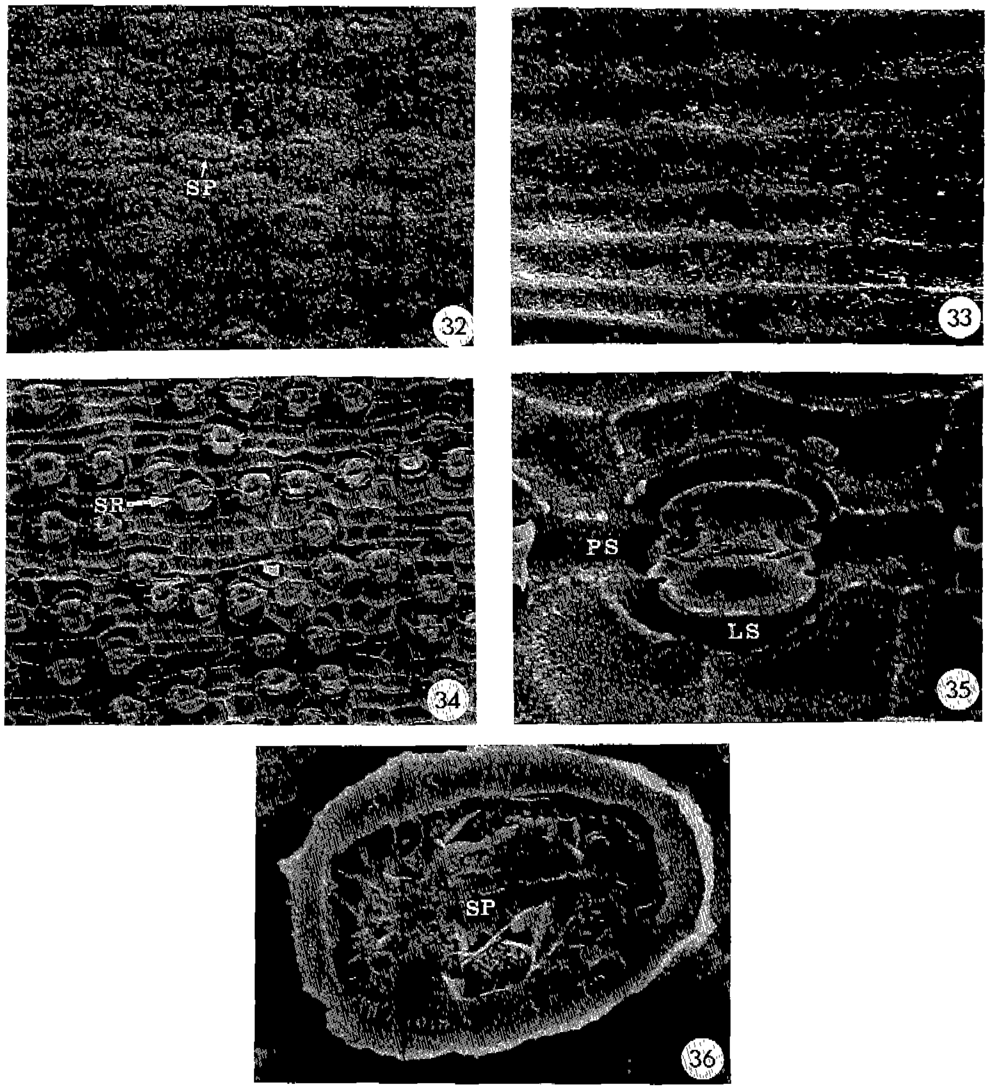
Epidermal cells are rectangular and short with vertical end wall (Figs. 30, 31). Some irregular shapes occur, especially around stomates (Fig. 29). Anticlinal wall of epidermal cells is straight (Figs. 30, 31). The cuticle of epidermal cell walls, however, has an irregualr outer flange by the extension of cuticle toward the hypodermal level (Figs. 30, 31). The periclinal wall of epidermal cells shows granular surface with many tubercles (Figs. 30, 31), but that of epidermal cell within stomatal band shows pitted at middle part and granulated near the margin (Fig. 28).

Cephalotaxus koreana Nakai

Adult leaves are spreading being linear to slightly falcate, spirally arranged appearing 2-ranked and homofacially flattened. They are in the range of 2-4 cm long and 0.2-0.4 cm wide with acuminate top and cuneately obtuse base, and have a rudimentary twisted petiole. Stomates are in two broad bands, being occupying nearly the entire area except for margin and robust mid-vein, and run for the entire length on abaxial leaf surface (Table 1).

The outer cuticular surface (Table 2) : Adaxial and abaxial surface are undulating in both stomatal areas and stomatal free regions (Figs. 32, 33). Papillae are not developed (Figs. 32, 33). Florin rings are virtually absent, with, at most, the stomatal orifice being surrounded by a slightly raised area. The stomatal groove is not developed (Fig. 32). Stomatal orifices are elliptical. Stomates are plugged with granules and fine rods (Figs. 32, 36).

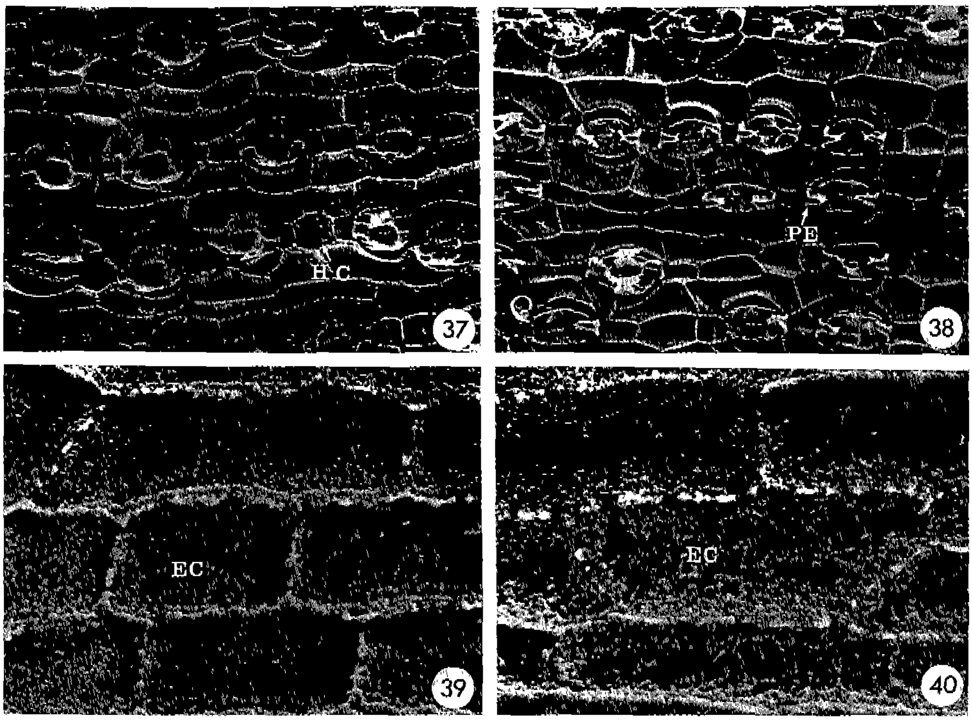
The inner cuticular surface (Table 3) : Stomatal rows are mostly continuous and are often separated by less than three rows of epidermal cells (Figs. 34, 37 and 38). The number of stomatal rows within a stomatal band ranges fifteen to twenty. Within stomatal rows, stomates are separated by three or fewer epidermal cells (Figs. 34, 37 and 38). These cells are usually shorter than epidermal cells between stoma-



Figs. 32-36. Scanning electron micrographs of the cuticular micromorphology of *Cephalotaxus koreana* Nakai. Fig. 32. Outer view, abaxial side. Note the absence of Florin rings. ×330. Fig. 33. Outer view, adaxial side, showing undulating surface. ×450. Fig. 34. Inner view, abaxial side, showing the parallel arrangements of stomates. ×170. Fig. 35. Higher magnification of stomatal apparatus, showing subsididary cells. ×1,000. Fig. 36. Magnified stomatal plug, showing rod and granular plugged materials. ×3,700.

tal rows and in stomatal free regions (Figs. 34, 37 and 38). Stomatal orientation aligns parallel to the long axis of leaf (Figs. 34, 37 and 38). The subsidiary cell number in each stomatal apparatus is four with typical formation of the conifers of two polar and two subsidiary cells, but rarely five by dividing lateral subsidiary cells (Figs. 34, 35, 37 and 38). Stomatal complex is oval; however, the polar subsidiary cells usually project beyond a continuation of the external margins of the lateral subsidiary cells so that the stomatal apparatus does not have a smooth oval outline (Figs. 35, 37 and 38). Many hypoplastic stomates are within stomatal rows (Figs. 34, 37). Polar subsidiary cells are rectangular with vertical end wall and many of them are shared with neighbour stomates (Figs. 34, 35, 37 and 38). The groove near guard cells is not developed (Figs. 34, 35, 37 and 38).

The cuticular flange between subsidiary cells and epidermal cells is not well develop (Figs. 34, 35, 37 and 38). The cuticular flange, both, between guard cells and lateral subsidiary cells, and between guard



Figs. 37-40. Scanning electron micrographs of the cuticular micromorphology of *Cephalotaxus koreana* Nakai. Fig. 37. Inner view of stomatal region. Note the well developed flanges and hypoplastic cells. ×290. Fig. 38. Inner view of stomatal region, showing poorly developed flanges. ×330. Fig. 39. Inner view, abaxial side, showing the periclinal wall pattern of epidermal cell. ×850. Fig. 40. Inner view, abaxial side, showing the periclinal wall pattern of epidermal cell. ×950.

cells, is well developed so that guard cells are almost covered with cuticular flange (Figs. 34, 37, 38). Polar extensions are narrow and thick, and well develop so that they unite with the flange of guard cells and lateral subsidiary cells (Figs. 34, 37, 38). Cuticle of guard cell surface is smooth but slightly pitted near the edge and that of subsidiary cells is finely pitted (Fig. 35).

Epidermal cells are rectangular and moderately short, with occasionally oblique end wall (Figs. 39, 40). Some irregular shapes occur, especially around stomates (Figs. 34, 38). The anticlinal wall of epidermal cells is straight and the cuticular flange of them is irregular and interrupted (Figs. 39, 40). Periclinal wall of epidermal cells shows somewhat a mixture of pitted and granular surface without tubercles (Figs. 39, 40).

DISCUSSION

Since Florin's extensive works of extant and fossil conifers with light microscope (Florin, 1920, 1931), cuticle micromorphology of extant gymnosperms using scanning electron microscope has not been paid much attention to except limited studies for the paleobotanical purpose (Oladele, 1981a, b; Stockey and Ko, 1986; Wells and Hill, 1989; Hill and Carpenter, 1991; Hill and Pole, 1992; Hill *et al.*, 1993; Stockey and Atkinson, 1993). The current study deals with the cuticle micromorphology of five species of Korean gymnosperms with scanning electron microscopy including reexamination of their leaf morphology.

All the five species have hypostomatic leaves. However, on *Ginkgo biloba* there are very small number of stomates on adaxial side of some leaves. It is also well known that amphistomatic leaves occurred more widely in fossil members of this family (Ohana and Kimura, 1986). Therefore, it could be suggested that the appearance of adaxial stomates from some leaves of *G. biloba* may be a fact worthy to be studied further on paleobotanical viewpoint.

Outer cuticular surface is basically undulating even though the degree of undulations differs among taxa investigated. Florin rings are developed in two species, *G. biloba* and *Taxus cuspitata*, but absent in three, *Torreya nucifera, Cephalotaxus koreana*, and *Cycas revoluta*. *G. biloba* moderately develope Florin rings which is lobed and interrupted, and those of *T. cuspidata* are prominent and surrounded by groove with high, lobed and interrupted ridge. In considering the studies of other gymnospermous plants which also show variability of Florin ring types (Oladele, 1981a, b), it could be suggested that the shape of Florin ring might be useful for the identification of gymnosperm fossils on family level.

The inner cuticular surface of conifers, taxads and cycads was studied with LM (Florin, 1920, 1931; Pant and Nautiyal, 1963) and Araucariaceae with scanning electron microscope (Stockey and Ko, 1986; Stockey and Taylor, 1987). According to Florin (1931), the inner cuticular surface of guard cell of *Cephalotaxus* is covered with unidentified organic materials. However, it is revealed thourgh this study that the covering material of guard cell of *C. koreana* is extension of the cuticular flange. In addition, the guard cell of *T. cuspidata* is also covered with cuticular flange. Hypoplastic stomates are also found on the *C. koreana* as Florin's description.

In the course of the study of Cycadales, Pant and Nautiyal (1963) described cuticular structure of 13 species of genus *Cycas*, and suggested that porous wall is a characteristic feature of this genus. In our study, porous periclinal wall was also found in *C. revoluta*. The porous wall is corresponded to the type IV of their classification.

The cuticle micromorphology with scanning electron microscope, especially inner cuticular surface has not been studied yet among gymnosperms except Cupressaceae and Araucariaceae (Oladele, 1981 a, b; Stockey and Ko, 1986; Stockey and Atkinson, 1993). On inner surface view, stomatal apparatus in five species is basically oval. However, polar subsidiary cells of *T. nucifera* join at their margin, whereas those of *T. cuspidata* and *C. koreana* usually project beyond a continuation of the external margins of lateral subsidiary cells. On polar extension, *C. revoluta* and *G. biloba* are broad and thick, *T. nucifera* and *C. koreana* are narrow and thick, and T. cuspidata is broad and thin. Wall pattern of epidermal cells is various, but mostly pitted and granular. Anticlinal wall of *T. nucifera, T. cuspidata*, and *C. koreana* is straight. The wall pattern of guard cells is smooth except *G. biloba* whose pattern is granular. However, that of subsidiary cells often shows granular or pitted on both walls. The number of subsidiary cells is 4-6 in *G. biloba, C. koreana*, and *T. cuspidata*, and 5-11 in *C. revoluta* and *T. nucifera*. Stomatal row is continuous in *T. cuspidata* and *C. koreana*, scattered in *G. biloba*, and alternative arranged between adjacent rows in *T. nucifera*.

Conclusively, these data could be morphologically employed in terms of the identifications of fossil vegetative remains as well as the taxonomy of living gymnosperms.

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韓國產 나자植物 잎의 큐티클 微細形態
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적 요

한국산 나자식물중 소철과, 은행나무과, 주목과, 그리고 개비자나무과 등 4 과의 잎의 큐티클 미세형태를 주사전자현미경으로 조사하였다. 잎의 향축면 및 배축면의 내측 및 외측 큐티클의 형태을 상세하게 기재하였다. 즉 플로린환 (Florin ring), 氣孔口 (orifice)와 氣孔덮게 (plug), 모용 (trichome) 등의 유무와 그들의 형태, 표피세포의 형태와 그의 병층벽 및 수층벽의 表面構造, 表皮細胞의 큐티클 伸張, 표피세포, 공변세포 그리고 부세포의 플랜지 (flange) 형태, 氣孔域線 (stomatal band)과 氣孔列線 (stomatal row)의 수, 氣孔裝置의 極伸張 (polar extension), 부세포의 수, 氣孔環溝 (groove), 공변세포 및 부세포의 표면구조 등을 기재하였다. 본 연구에서 밝혀진 큐티클 미세형태는 많은 경우 이전의 연구에서 확인된 바 없는 특징들이었다. 더욱이 조사된 5종 식물 모두는 분류군별로 형태학적 및 분류학적으로 가치가 있는 뚜렷한 큐티클 미세형태를 나타내었다.

주요어 : 큐티클, 한국산 나자식물 (소철속, 은행속, 비자나무속, 주목속, 개비자나무속)

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