목재공학15(4) : 1~11(原著)
Wood Sci., & Tech. 15(4) : 1~11, 1987

The Distribution and Shape of Crystals in the Xylem of Korean Hardwoods*[1]

Phil Woo Lee*[2] · Young Geun Eom*[2] · Youn Jib Chung*[2]

韓國產 濶葉樹材 木部에 있어서의 結晶 分布 및 形態*[1]

李 弼 宇*[2] · 嚴 永 根*[2] · 鄭 然 楫*[2] ·

要 約

韓國產 濶葉樹材의 27科 45屬 82種을 選定하여 이들 木部에 存在하는 結晶의 形態 및 分布를 調査함으로써 얻은 結果를 간단히 要約하면 다음과 같다.

1. 多面體形의 結晶이 가장 많이 觀察되었으며 集晶도 종종 觀察되었으나 柱晶은 극히 일부 樹種에서만 나타났다.

2. 이러한 結晶은 주로 軸方向柔組織 및 放射組織에 存在하였으며 髓, 타일로시스, 眞正木纖維 및 髓斑點에서도 그 存在가 確認되었다.

3. 대부분의 結晶細胞는 再分裂 및 擴大를 통하여 變形되므로써 結晶을 지니지 않는 細胞와 그 形態的인 차이를 나타내었다.

1. Introduction

Many types of inclusions are common in cell lumina of hardwoods and one of these inclusions is crystal.

On these crystals much work has been widely discussed since long. Jeffrey[10] mentioned that crystalligenous cells containing large crystal of calcium oxalate were appeared in phloem of *Tilia americana*, and Chattaway[4] i tigated the presence of crystal sand, acicular, and raphid in axial parenchyma and ray of woody plants. Panshin and de Zeeuw[15] described that crystals were common in the upright cells but uncommon in the procumbent cells of rays and Esau[7] pointed out that various shapes of calcium oxalate crystals were prominently present in plants. The distribution and shape of crystals in neotropical Sapotaceae was reported by Kukachka,[11] and Core, Côté, and Day[5] recorded the presence of crystals in ray or longitudinal parenchyma of *Juglans nigra, Fagus grandiflora,* and *Carya* species and said that these crystals were of minor diagnostic significance since their presence might be helpful but the absence might be due to chance.

Also, Panshin and de Zeeuw[16] described that crystals, mostly of calcium compounds, were observed in ray cells in great variety of forms than in axial parenchyma. Butterfield and Meylan[3] referred that crystals were formed in axial and ray parenchyma, septate fiber, tyloses, and vessel, and

*1. 接受 8月 24日 Received August 24, 1987.
*2. 서울大學校 農科大學 College of Agriculture, Seoul National University, Suwon 170, Korea.

their presence in vessel were associated with fungal contaction. They also mentioned that crystals were enclosed in a sac in the ray cells of *Griselinia lucida* and *Melicytus ramiflorus* and raphides of calcium oxalate were common in woody monocotyledones. Nanko and Côté[14] in their work on phloem elements of 13 hardwoods grown on southern pine sites observed various forms of crystals and confirmed that most of these crystals were calcium oxalate. The large lump of dense calcium carbonate, on the other hand, were referred to as stone by Desch and Dinwoodie[6].

In computerized hardwood identification by IAWA[9], the distribution, shape, and presence of crystals were adapted as criteria. On these crystals, Fahn[8] mentioned that the most common were calcium oxalate of various shapes, but calcium carbonates were rare in high plants and this type of crystal was associated with cystolith in some plants.

In investigation of *Terminalia solomonensis, Terminalia calamansanai, Litsea timoriana, Dillenia* and *Shorea* species, Taniguchi, Okamura, Harada, and Nakato[18] found that most crystals were polyhedral of calcium oxalate monohydrate and said that these crystals could be used as criteria in wood identification since their shape and distribution within a given taxon varied from species to species.

Rury[17] investigated the crystals in ray and axial parenchyma of Erythroxylaceae and Barajas-Morales[1] observed chambered crystals in *Coccoloba liebmanii, Caesalpinia eriostachys, Apoplanesia paniculata,* and irregular crystals in vessel element of *Pithecellobium mangense.*

Recently, Taniguchi, Lee, Fukazawa, and Harada[19] reported that the crystals in vessel elements of Japanese poplar heartwood were calcium carbonate with a calcite structure and those in phloem parenchyma cells were calcium oxalate monohydrate and their shapes were various in both vessel elements and phloem parenchyma cells. Also Martijena[13] in his work on *Lithraea ternifolia* obse: ed abundant crystalliferous chambered cells, ar . Lee and Eom[12] in their investigation of 50 veneer species grown in Korea found crystals in ray or axial parenchyma cells of *Quercus, Acer,* etc.

In spite of their usefulness as criteria for wood identification no systematic studies have been conducted on crystals in Korean hardwoods, therefore this study was executed to investigate their distribution and shape in xylem.

2. Materials and Methods

The wood samples of 27 families, 45 genera, 82 species selected from collections in Wood Anatomy Lab., Department of Forest Products and Technology, College of Agriculture, Seoul National University were investigated(Table 1).

From each species, wood blocks, ca. one cubic centimeter, were obtained and soaked in water for one month before softening. The softening was carried out in autoclave[12] and preserved in absolute, glycerine, and wate 1 : 1 : 1(v/v) mixture[2].

Cross, radial, and tangential sections, 20 μm thick, obtained with sliding microtome were stained with safranin, dehydrated with ethanol and xylene, and mounted with Canada balsam[20].

Finally, Canon AE-1 type camera attached to Olympus Model K microscope by Canon Photomicro Unit F was used for taking microphotographs[12].

3. Results and Discussion

The results from the investigation on crystals

Table 1. The distribution and shape of crystals in Korean hardwoods

Famlily and species name	Axial parenchyma	Ray		Remark
		Square or upright cell	Procumbent cell	
Aceraceae				
Acer ginnala Max.	PO(c)	–	–	
Acer mandshuricum Max.	–	–	–	
Acer mono Max.	PO(c)	–	–	
Acer palmatum Thunb.	PO(r)	–	–	
Acer tegmentosum Max.	–	–	–	
Acer triflorum Kom.	PO(r)	–	–	
Anacardiaceae				
Rhus chinensis Miller	–	PO(r), DR(r), ST(r)	PO(r), DR(c), ST(r)	
Araliaceae				
Kalopanax pictus Nakai	–	–	–	
Betulaceae				
Alnus hirsuta (Spach) Rupr.	–	–	–	
Alnus hirsuta var. *sibirica* Schneider	–	–	–	
Alnus japonica Steudel	–	–	–	
Betula chinensis Max.	–	–	–	
Betula costata Trautv.	–	–	–	
Betula davurica Pallas	–	–	–	
Betula platyphylla var. *japonica* Hara	–	–	–	
Betula schmidtii Regel	–	–	–	
Carpinus cordata Blume	–	PO(r)	PO(r)	
Carpinus laxiflora Blume	–	PO(r)	PO(r)	PO(r) in pith fleck
Carpinus tschonoskii Max.	PO(r)	PO(r)	PO(r)	
Bignoniaceae				
Catalpa ovata G. Don	–	–	–	
Cornaceae				
Cornus controversa Hemsley	–	–	–	
Cornus kousa Buerger	–	–	–	
Cornus walteri Wangerin	–	–	–	
Ebenaceae				
Diospyros kaki Thunb.	PO(r)	–	PO(r)	
Euphorbiaceae				
Sapium sebiferum (L.) Roxb.	PO(r)	–	–	PO(r) in tylosis, PO(c) in pith
Fagaceae				
Castanea crenata S. et Z.	–	–	–	
Castanopsis cuspidata var. *sieboldii* Nakai	PO(c)	–	–	

Famlily and species name	Axial parenchyma	Ray		Remark
		Square or upright cell	Procumbent cell	
Fagus crenata var. *multinervis* (Nakai)T. Lee	–	–	–	
Quercus acuta Thunb.	PO(c)	–	PO(r)	
Quercus acutissima Carr.	PO(r)	–	–	
Quercus aliena Blume	PO(r)	–	–	
Quercus dentata Thunb.	PO(r)	–	DR(r)	
Quercus mongolica Fischer	PO(r)	–	–	
Quercus myrsinaefolia Blume	PO(a)	–	PO(a)+	+ mostly in compound ray
Quercus serrata Thunb.	PO(c)	–	PO(c)+	+ mostly in compound ray
Quercus variabilis Blume	PO(c)	–	PO(r)	
Juglandaceae				
Juglans mandshurica Max.	–	–	–	
Juglans sinensis Dode	–	–	–	
Platycarya strobilaceae S. et Z.	PO(r), ST(r)	PO(c)	PO(r)	PO(r), ST(c) in libriform fiber
Lauraceae				
Cinnamomum camphora S.	–	–	–	
Cinnamomom japonicum S.	–	–	–	
Machilus thunbergii S. et Z.	–	–	–	
Neolitsea sericea (Bl.) Koidz	–	–	–	
Leguminosae				
Gleditsia japonica var. *koraiensis* Nakai	PO(r)	–	DR(c)	
Maackia amurensis Rupr. et Max.	–	–	–	
Robinia pseudoacacia L.	PO(c)	PO(r)	PO(c)	
Sophora japonica L.	–	DR(r)	DR(r)	
Meliaceae				
Cedrela sinensis Juss.	–	PO(r)	–	
Melia azedarach var. *japonica* Makino	PO(r)	–	–	
Moraceae				
Morus alba L.	PO(r)	PO(c)	PO(r)	
Oleaceae				
Fraxinus mandshurica Rupr.	–	–	–	
Fraxinus rynchophylla Hance	–	–	–	
Syringa reticulata mandshurica (Mak.) Hara	–	–	–	
Platanaceae				
Platanus acerifolia Willd.	–	–	PO(r)	
Platanus occidentalis L.	–	–	PO(r)	

Famlily and species name	Axial parenchyma	Ray		Remark
		Square or upright cell	Procumbent cell	
Rhamnaceae				
Berchemia berchemiae-folia (Mak.) Koidz	PO(r)	PO(c)	PO(r)	
Hovenia dulcis Thunb.	PO(r)	PO(c)	PO(r)	
Rosaceae				
Prunus leveilleana Koehne	PO(r), DR(r)	–	–	
Prunus maackii Rupr.	–	–	–	
Prunus mandshurica var. *glabra* Nakai	–	DR(r)	DR(r)	
Prunus padus L.	–	–	–	
Prunus sargentii Rehder	PO(r), DR(r)	PO(r), DR(r)	PO(r), DR(r)	
Prunus serrulata var. *Spontanea* Wilson	–	–	–	
Prunus takesimensis Nakai	DR(r)	DR(r)	DR(r)	
Rutaceae				
Phellodendron amurense Rupr.	PO(r), ST(r)	–	ST(r)	
Salicaceae				
Populus alba-grandulosa L.	–	–	–	
Populus maximowiczii Henry	–	–	–	
Salix koreensis Anderson	–	–	–	
Scrophulariaceae				
Paulownia coreana Uyeki	–	–	–	
Simaroubaceae				
Ailanthus altissima (Mill.) Swingle	–	–	–	
Sterculiaceae				
Firmiana simplex (L.) W.F. Wight	PO(r), DR(r)	PO(r), DR(r)	PO(r), DR(r)	
Styraceae				
Styrax japonica S.et Z.	PO(r)	–	–	
Theaceae				
Stewartia koreana Nakai	–	–	–	
Tiliaceae				
Tilia amurensis Rupr.	–	–	–	
Tilia mandshurica Rupr. et Max.	–	–	–	

Famlily and species name	Axial parenchyma	Ray		Remark
		Square or upright cell	Procumbent cell	
Ulmaceae				
Celtis jessoensis Koidz	–	PO(r), DR(r)	PO(r), DR(r)	
Celtis sinensis var. *japonica* Nakai	PO(r), DR(r)	PO(c), DR(c)	PO(r), DR(r)	
Hemiptelea davidii Pl.	–	–	–	
Ulmus davidiana var. *japonica* Nakai	–	–	–	
Ulmus parviflora var. *coreana* Uyeki	–	–	–	
Ulmus pumila L.	–	–	–	
Zelkova serrata Makino	–	PO(c)	PO(r)	

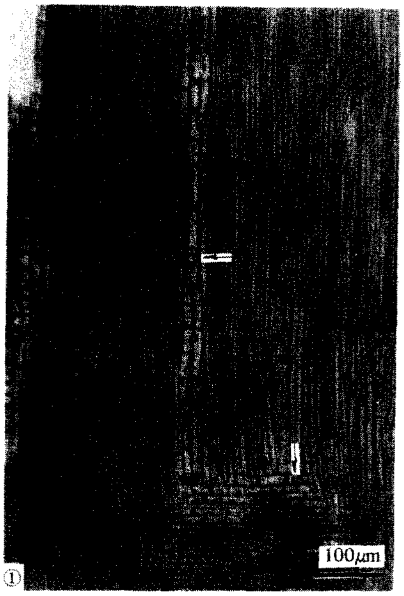
* PO, DR, and ST means the polyhedral, druse, and styloid, respectively
** r, c, and a in parenthesis means rare, common, and abundant in content, respectively
*** – means the absence of crystals

in the xylem of Korean hardwoods were summarized as Table 1. In this research, the shape of crystals followed the classification by Taniguchi, Okamura, Harada, and Nakato[18] and the content of crystals in each shape distributed in each type of tissues was denoted as rare, common, and abundant on the basis of standard samples by us (Fig. 1 – 3).

Of the 27 families, 45 genera, 82 species investigated, 3 shapes of crystals were observed in 17 families, 23 genera, 40 species as follows: polyhedral crystals in 17 families, 22 genera, 37 species, druses in 6 families, 7 genera, 11 species, and styloids in 3 families, 3 genera, 3 species. We think these observation corresponds with the reports by Panshin and de Zeeuw[15,16] and Taniguchi, Okamura, Harada, and Nakato[18] that the most common crystals were polyhedral (e.g. hexahedral and rhombidal) but druses, styloids, etc. were sometimes contained.

In the distribution of these crystals, we could observe that polyhedral crystals were mostly occurred in axial and ray parenchyma cells but rarely in pith flecks, tyloses, libriform fibers, and pith (Fig. 1 – 8 and 15). And we think our observation of more druses in ray parenchyma cells than in axial parenchyma cells (Fig. 9 – 10) may be agreed in the opinion by Panshin and de Zeeuw[16] that crystals were observed in ray parenchyma cells in great variety of forms than in axial parenchyma cells. The styloids, as their presence in xylem or phloem was confirmed by Esau[7], Nanko and Côté[14], Fahn[8], and Taniguchi, Okamura, Harada, and Nakato[14] were formed in axial and ray parenchyma cells and libriform fibers (Fig. 8 – 9 and 12).

On the distribution of these crystals, Chattaway[4] and Butterfield and Meylan [3] referred that they were commonly found in the ray or axial parenchyma cells and less frequently in septate fibers, tyloses, and vessel elements. Especially, Butterfield and Meylan[3] reported that the presence of crystals in vessel elements was associated with fungal contaction. Differently from the description of Panshin and de Zeeuw[15] that crystals were common in upright cells but uncommon in procumbent cells of rays, we could observe these crystals frequently both in procumbent cells and upright or squre cells (Fig. 4, 9 – 10, and 12 – 14). These observation corresponds with the result by Chattaway[4] and later description of Panshin and de Zeeuw[16]. Furthermore, most of the crystals



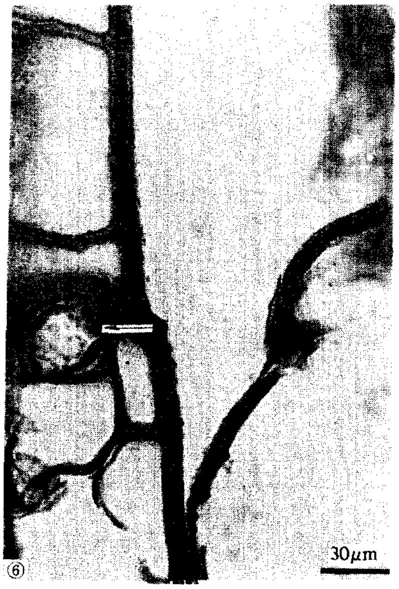


Fig. 1. Rare content of polyhedral crystals (↑) in aixal and ray parenchyma cells of *Berchemia berchemiaefolia*(Mak.) Koidz.

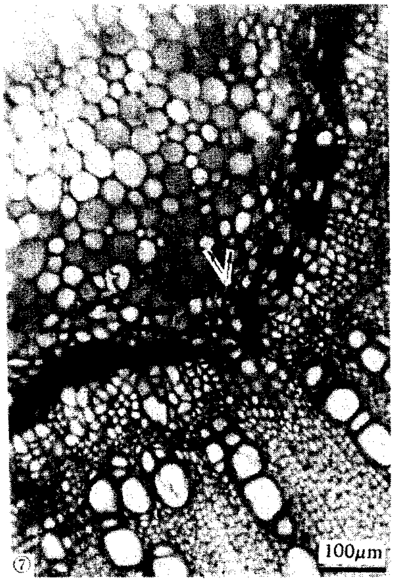
Fig. 2. Common content of polyhedral crytals (↑) in axial parenchyma cells of *Quercus acuta* Thunb.

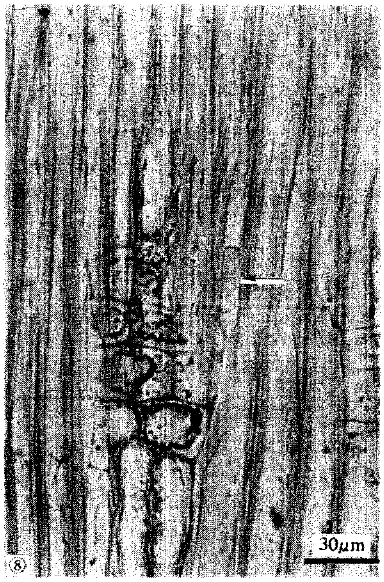
Fig. 3. Abundant content of polyhedral crystals (↑) in axial parenchyma cells of *Quercus myrsinaefolia* Bl.

Fig. 4. Polyhedral crystals (↑) in procumbent cells of *Platanus acerifolia* Willd.

Fig. 5. Polyhedral crystals (↑) in pith fleck of *Carpinus laxiflora* Bl. and sclerosed, pitted tylosis is shown on left side of this pith fleck.

Fig. 6. Polyhedral crystal (↑) in tylosis of *Sapium sebiferum*(L.) Roxb.





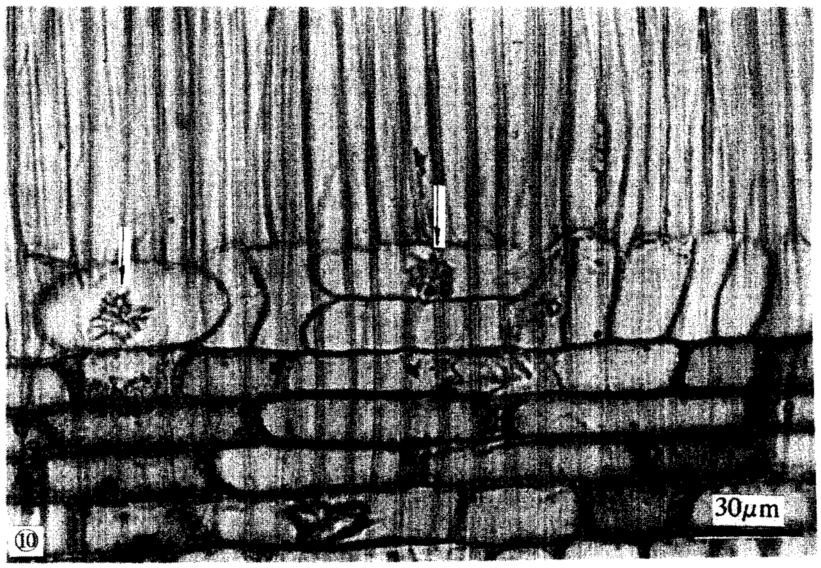
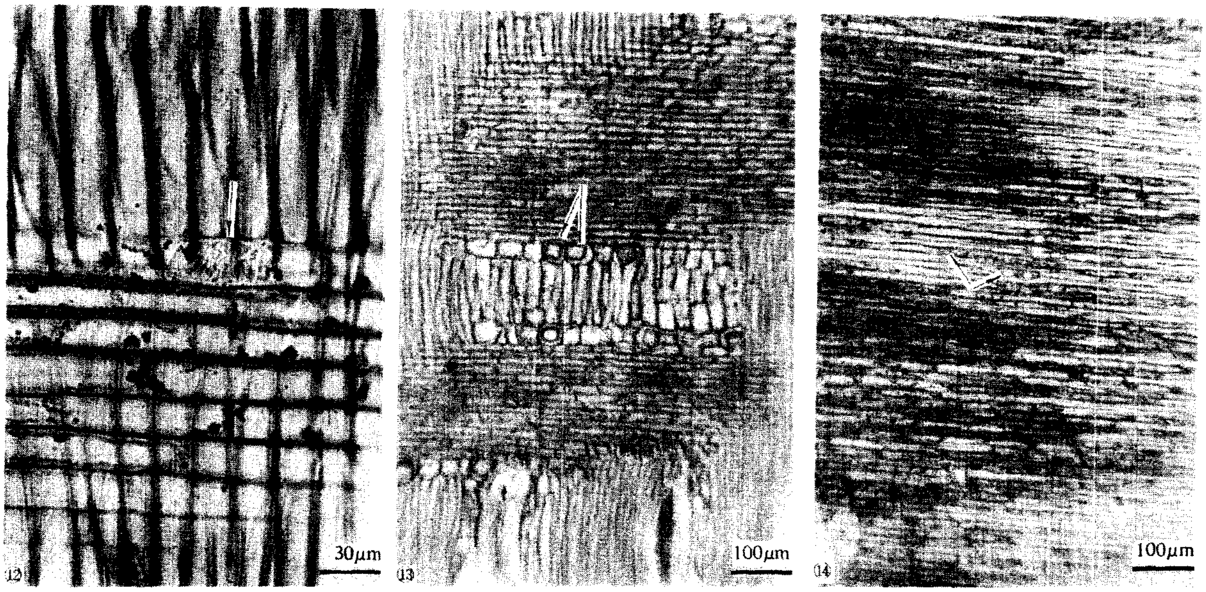


Fig. 7. Polyhedral crystals (↑) in pith of *Sapium sebiferum*(L.) Roxb.
Fig. 8. Styloid (↑) and polyhedral crystal (▲) in libriform fibers of *Platycarya strobilaceae* S. et Z.
Fig. 9. Druses (↑) in procumbent cells of *Gleditsia japonica* var. *koraiensis* Nakai.
Fig. 10. The transformed upright cells containing druses (↑) in *Rhus chinensis* Miller.
Fig. 11. Styloids (↑) in axial parenchyma cells of *Phellodendron amurense* Rupr.



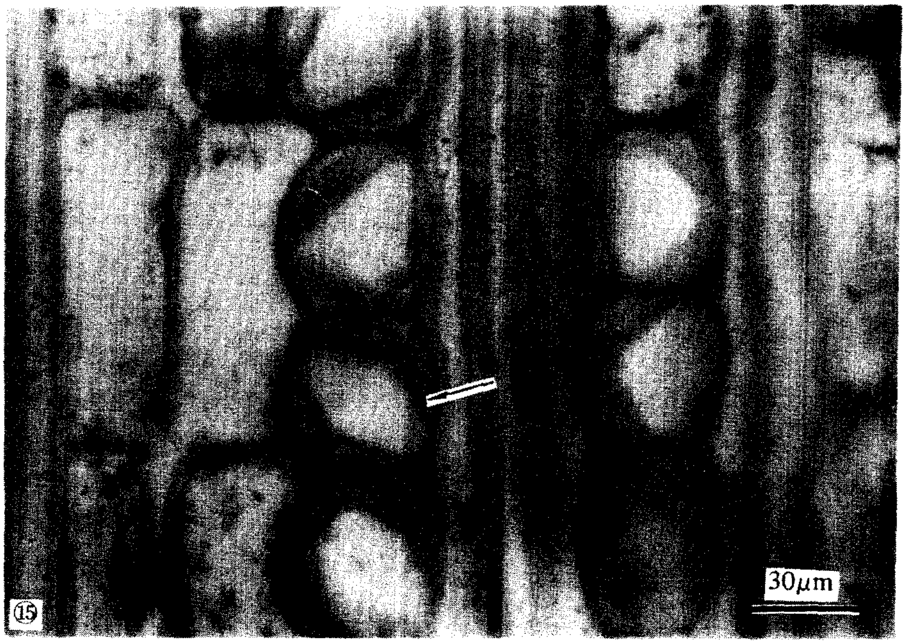


Fig. 12. Styloid (↑) in procumbent cell of *Phellodendron amurense* Rupr.
Fig. 13. Polyhedral crystals (↑) in square cells of *Zelkova serrata* Makino.
Fig. 14. Polyhedral crystals (↑) in procumbent cells of compound ray in *Quercus serrata* Thunb.
Fig. 15. Polyhedral crystals (↑) in axial parenchyma cells of *Quercus acuta* Thunb.

were largely contained in procumbent cells of compound rays in the species of *Quercus myrsinaefolia* and *Quercus serrata* (Fig. 14).

On the other hand, most of the crystal-bearing cells were usually different from the cells devoid of crystals in that those of axial parenchyma and those in inner part of rays were enlarged or shortened in length by subdivision (Fig. 4 and 15) and those on the upper and lower margin of rays were enlarged or transformed into shape of procumbent cell through enlargement or subdivision (Fig. 10 and 13). In relation to these, Chattaway[4] noted four modifications as follows: subdivision of the containing cell, enlarged cells (idioblasts), sclerosed cell wall of the containing cell, and variation in size and number of the crystals occurring in a single cell.

4. Conclusion

The shape and distribution of crystals in xylem of Korean hardwoods, 27 families, 45 genera, 82 species were investigated and discussed, and the results were as follows:

1. The most common crystals were polyhedrals, and druses were observed often but styloids were limited in few species.
2. These crystals were mostly distributed in axial and ray parenchyma cells but rarely in pith, tyloses, libriform fibers, and pith flecks.
3. Most of the crystal-bearing cells were different from the cells devoid of crystals in shape by the modifications through subdivision or enlargement.

Literature Cited

1. Barajas-Morales, J. 1985. IAWA Bull. n. s., Vol. 6(4): 355-364.
2. Berlyn, C. P. and J. P. Miksche. 1976. Botanical microtechnique and cytochemistry. 1st ed., The Iowa State Univ. Press, 326pp.
3. Butterfield, B. G. and B. A. Meylan. 1980. Three-dimensional structure of wood, An ultrastructural approach. 2nd ed., Chapman and Hall, 103pp.
4. Chattaway, M. M. 1955, 1956. Tropical Wood No. 102; 55-75, No. 104; 100-124.
5. Core, H. A., W. A. Côté, and A. C. Day. 1979. Wood structure and identification. 2nd ed., Syracuse Univ. Press, 182pp.
6. Desch, H. E. and J. M. Dinwoodie. 1981. Timber its structure, properties, and utilisation. 6th ed., Macmillan press Ltd., 410pp.
7. Esau, K. 1977. Anatomy of seed plants. 2nd ed., John Wiley & Sons Inc., 550pp.
8. Fahn, A. 1982. Plant anatomy. 3rd ed., Pergamon Press, 544pp.
9. IAWA. 1981. IAWA Bull. n. s., Vol. 2(2-3): 99-110.
10. Jeffrey, E. C. 1917. The anatomy of woody plants. The Univ. of Chicago Press, 478pp.
11. Kukachka, B. F. 1978 - 1982. Wood anatomy of the neotropical Sapotaceae. Reserch Paper FPL 325-331, 349-354, 358-363, 371-374, 395-398, 416, 417, 419-426, USDA, Forest Service, Forest Product Lab.
12. Lee, P. W. and Y. G. Eom. 1987. Jour. of The Kor. Wood Sci. & Tech., 15(1): 22-55.
13. Martijena, N. 1987. IAWA Bull. n. s., Vol. 8(1): 47-52.
14. Nanko, H. and W. A. Côté. 1980. Bark structure of hardwoods grown on southern pine sites. Syracuse Univ. Press, 56pp.
15. Panshin, A. J. and C. de Zeeuw. 1970. Textbook of wood technology. Vol. 1, 3rd ed., MrGraw-Hill, 705pp.
16. Panshin, A. J. and C. de Zeeuw. 1970. Text-

book of wood technology. 4th ed., McGraw-Hill, 722pp.

17. Rury, P. M. 1985. IAWA Bull. n. s., Vol. (6): 365-397.

18. Taniguchi, T., K. Okamura, H. Harada, and K. Nakato. 1984. Ultrastructure of calcium oxalate in woody plants. Proceed. of Pacific Regional Wood Anatomy Conference, Tsukuba: 115-117.

19. Taniguchi, K., K. Y. Lee, K. Fukazawa, and H. Harada. 1987. Mokuzai Gakkaishi, 33(1): 1-6.

20. The Japan Wood Research Society. 1985. Wood science laboratory book, I. Physics and engineering. Chugai Sangyo Chosakai, 346pp.