韓國林學會誌 78(3) : 287-301. 1989.
Jour. Korean For. Soc. 78(3) : 287-301. 1989.

Anatomical Studies on Tumorous Tissue Formed in a Stem of *Ailanthus altissima* Swingle by Artificial Banding and Its Subsequent Removing Treatment[1]

—Characters of Individual Elements—

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人爲的인 밴드結締 및 解締處理로 形成된 가죽나무(*Ailanthus altissima* Swingle)樹幹의 腫瘍組織에 관한 解剖學的 硏究[1]

—組織 構成細胞의 特性—

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ABSTRACT

A tree of *Ailanthus altissima* Swingle was fastened with a plastic band, 19mm wide, around the stem 180cm above ground level and was left to grow under this condition for one year. By removal of this band the tumorous tissue gradually developed and the tree bearing distinct tumorous tissue, an overgrowth surrounding the stem, was harvested two years after the band removal. For the investigation of this tumorous part and its comparison with adjacent normal parts in the anatomical features of individual elements, the tumorous part and parts directly and 40cm above and below the tumorous part were obtained from the tree.

The tumor wood having remarkably wider growth increment occurred in the 3rd growth ring the first year after removal of the fastened band, and the barrier zone which delimited the discolored wood from the normal-colored wood inwards appeared in the intra-2nd growth ring produced during the fastened period in the tumorous part and the false ring-like zones equivalent to barrier zone were shown in the normal-colored 2nd growth rings of the parts directly and 40cm above and below the tumorous part, as well.

The tumor wood, the 3rd growth ring, and proportion of the 2nd growth ring formed after barrier zone in the tumorous part shared common characteristics in the irregular growth ring boundary, misshapen and shorter individual fibers and vessel elements, and large ray widths and heights. The springwood pores were smaller in diameter in the tumor wood, and the larger radial and smaller tangential diameters of summerwood solitary pores and individual pores consisting of pore multiples in proportion of the 2nd growth ring formed after the barrier zone were transformed into near-isodiametric in the tumor wood, the 3rd growth ring, in the tumorous part. Only in proportion of the 2nd growth ring formed after the barrier zone were transformed into near-isodiametric in the tumor wood, the 3rd growth ring, in the tumorous part. ray densities greatly increased. And the massive tumor wood was caused not by cell size

[1] 接受 1989年 6月 16日 Received on June 16, 1989.
This paper represents a portion of a dissertation submitted by Y.G. Eom in partial fulfillment of the requirements for Ph. D. degree from Graduate School, Seoul National University

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but by cell number because the radial and tangential diameters of fibers in the tumor wood, the 3rd growth ring, in the tumorous part were not sufficiently different from those in the same aged growth rings of the directly and 40cm above and below the tumorous part.

Key words : *tumorous tissue*, Ailanthus altissima swingle, *anatomy*, *individual elements*.

要 約

가죽나무(*Ailanthus altissima* Swingle) 樹幹의 地上高 180cm 部位에 19mm 너비의 플라스틱 밴드를 結締하여 1年間 放置한 후 이 밴드를 解締하여 주므로써 樹幹을 둘러싸는 圓盤形態의 過大한 肥大生長組織인 腫瘍狀組織(tumorous tissue)이 形成되고 이러한 腫瘍狀 組織의 圓盤과 上下에 位置한 正常形態의 圓盤을 採取하여 解剖學的 差異를 構成細胞의 特性면에서 調査 比較하였다. 腫瘍狀 部位에서는 異常的으로 넓은 年輪幅을 지니는 腫瘍材(tumor wood)가 밴드 解締다음 해인 第3年輪에서 形成되었으며 밴드 結締期間중에 生長한 第2年輪內에서는 內部로 發達된 變色材(discolored wood)와 外部로 發達한 正常色의 材를 구분하는 防禦帶(barrier zone)가 形成되어 있었으며 이 腫瘍狀 部位의 上下에 位置한 正常形態의 部位에서는 正常材色을 나타내는 第2年輪內에 防禦帶에 해당하는 僞年輪狀帶(false ring-like zones)가 形成되어 있었다.

腫瘍狀 部位에 있어서 腫瘍材인 第3年輪과 防禦帶후에 發達한 第2年輪部分은 不規則한 年輪界, 길이가 짧으며 非正常的인 形態를 나타내는 木纖維 및 導管要素, 높이와 폭이 큰 放射組織을 가진다는 면에서 서로 類似하였다. 그리고 腫瘍材인 第3年輪의 春材部 管孔의 直徑은 上下 正常部位의 第3年輪것보다 작은 것으로 나타났으며 防禦帶후에 形成된 第2年輪 部分의 秋材部 孤立管孔 및 複合管孔을 구성하는 개개의 管孔은 放射直徑이 接線直徑보다 더 큰 特性을 나타낸 반면 腫瘍材에서는 直徑이 거의 유사한 경향을 나타내었다. 또한 腫瘍狀 部位에 있어서는 防禦帶후에 形成된 第2年輪部分에서만 放射組織密度가 크게 증가한 特性이 관찰되었다. 腫瘍材인 第3年輪의 木纖維 直徑은 上下 正常部位의 第3年輪것과 거의 차이를 나타내지 않으므로 과대한 肥大生長組織인 腫瘍材는 細胞의 크기에 의해서가 아니라 細胞數의 增加에 의해 形成되었음을 알 수 있었다.

INTRODUCTION

When the cambium in growing season is injured or its normal activity is influenced by several causes, tree forms various abnormal tissues such as tumor wood. Tumors are growths of plants, animals, or men in which the normal processes of control are ineffective for some reason, so that continued cell division results in massive disorganized development(White, 1958b). As the above definition implies, tumor wood is a tumefied overgrowth tissue in comparision with adjacent normal wood.

The cause of tumor wood has not been identified completely but hypotheses suggesting genetic instability, irritation of cambium by insects and bacteria, seawater spray, or higher concentration of auxin have been proposed and none of these agencies has been known ever to produce a tumor wood by itself(White and Millington, 1954a, b ; White, 1958a, b ; Peterson, 1961 ; DeTorok, 1967 ; Rickey *et al*. 1974 ; Kramer and Kozlowski, 1979). The factors that cause formation of tumor woods, however, appear to have no influence on the growth of bark surrounding tumor wood because of normal appearance and thickness and no external and internal evidence of abnormal growth(Rickey *et al*. 1974).

These tumor woods can be produced either by an increase in the rate of formation of new cells or by prolongation of the growth period(White, 1958a ; Peterson, 1961 ; Tsoumis, 1965 ; White *et al*. 1967 ; Rickey *et al*. 1974). Although tumor woods are similar in appearance to burls, well

-known massive intumescenes, tumor woods are regarded as a different tissue from common burls found on oak, chestnut, beech, maple, willow, walnut, elm, mulberry, sequoia, and many other trees in that tumor woods have smooth, unfissured surfaces and relatively normal appearances suggesting gradual and progressive bowing out of cambium into almost spherical shape without any discontinuity through consistently more tangential divisions than in adjacent normal woods in each successive year but burls have rough, fissured surfaces frequently covered with undeveloped buds or fungating, overlapping, or concentric pattern of surfaces, suggestive of constant irritations of cambium (White, 1958a, b).

In the study on tumor wood of *Picea glauca*, White and Millington (1954b) noted that the character of tumor wood itself was not greatly altered except only wider annual ring than in normal wood but tumor wood tissues were composed of less regular tracheids possessing large lumina and bordered pits more often paired and characterized by a less regular formation of resin canals. White (1958a) in a summarized report on tumor wood of *Picea glauca* described that transverse sections showed many times as many cells in each annual ring in tumor wood, counted radially, as in the corresponding normal parts and the only apparent difference was a somewhat thinner secondary cell wall, resulting in the tumor wood being softer and more cheesy in texture than normal wood. Peterson (1961) suggested that tumor woods on *Pinus contorta*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Abies lasiocarpa*, and *Picea engelmannii* appeared similar and shared anatomical characteristics in that modified xylem extened from near the pith to the cambium in a steadily enlarging conical zone, tumor xylem cells were usually not much larger than those in healthy tissue but 1.1 to 10.0 times more cells were produced along a given radius in a tumor than nearby outside the tumor, tumor xylem contained normal percentages of ray parenchyma and was not modified by deposition of resins or other incrusting materials, and the bark of tumors was not modified. He stated that all of these observations were in accord with the report of White (1958b) on tumor woods of *Picea glauca*.

Tsoumis (1965) showed that tumor wood of *Picea glauca* differed from normal wood in macroscopic and microscopic characteristics. He found the tumor wood to be characterized by wider growth rings and lighter weight macroscopically and the tumor wood tissues to be somewhat disorganized, especially in a greater number of cells per growth ring, variable width of adjoining cell files, abnormally large cell lumina, hazy walls and appearance of bordered pits on transverse sections as if seen in radial view, numerous traumatic resin canals arranged in tangential lines, and formation of irregular strand tracheids microscopically. In addition, tumor tracheids were known to be usually curved, sometimes acquiring bizarre shapes, and also shorter and relatively wider than normal wood tracheids with often variation of the width along their length. In the study concerning growth of tumors on *Picea glauca*, White *et al*. (1967) reported that yearly production of xylem cells ranged widely from growth rings of a single cell radial width in normal wood to growth rings of 800 or more cells width in tumor wood but the corresponding growth in phloem never exceeded a yearly increment of 10 cells even in the most rapidly growing tumors. They concluded that the massive size of tumor wood was brought about not by prolongation of the growth period but by acceleration of growth and this acceleration produced tumor wood abnormal in microscopic cellular structure and specific gravity.

Rickey *et al*. (1974) indicated in the examination of a number of tumor woods on *Picea sitchensis* that the tumor wood originated at the center of the stem or root as a result of some change at the growing tip and this change caused the xylem cells to divide and enlarge more rapidly than normal wood, ultimately forming a tumor wood. And they showed that the tumored tissue looked like normal wood in that it had annual rings and definite sapwood and heartwood zones and noted that the trunk tumor wood had no visible evidence of compression wood, whereas the trunk of affected tree above and below the tumor wood contained about 30% compression wood. They also found the tumor wood to have short, curved, and twisted tracheids, and numerous traumatic resin canals but to show no apparent abnormalities in wood rays and bark.

Recently, Tsoumis *et al*.(1988) showed that briarwood, a tumor-like outgrowth of *Erica arborea* developed between root and stem, had shorter and irregular fibers in comparison to stem wood, usually irregular structure, and amorphous or crystal enclosures in cell cavities.

Although some anatomical studies on tumor woods in softwoods have been conducted(White and Millington, 1954b ; White, 1958a, b ; Peterson, 1961 ; Tsoumis, 1965 ; White *et al*. 1967 ; Rickey *et al*. 1974), poor information is available concerning anatomy of tumor woods on hardwoods (Tsoumis *et al*. 1988).

The purposes of this study were to investigate anatomical characteristics of artificial tumorous tissue which formed after removing of a 19mm wide plastic band fastened before the active growing season around the stem and then kept for one year, and also to compare anatomically this tumorous tissue with adjacent normal ones in *Ailanthus altissima* Swingle, one of the fast-growing hardwood species in Korea.

MATERIALS AND METHODS

The sample chosen was *Ailanthus altissima* Swingle, one of the fast-growing hardwood species in Korea, bearing tumorous tissue which formed after removal of a plastic band fastened around the stem for one year. The sample tree growing in the previous home garden of my major professor located in Singil 7-dong, Youngdeungpo-gu, Seoul 150-057, Korea, was fastened with a plastic band of 19mm width around the stem at 180cm above the ground level in mid-June 1985 and this sample tree was grown under this condition for one year(Fig. 1B). The tumorous tissue began to develop after removing of the fastened plastic band in mid-June 1986, and the sample tree bearing distinct tumorous tissue was cut down in early April 1988(Fig. 1A).

As shown in Fig. 1C, five sample discs, 2cm thick, were taken at center of tumorous part, contiguous parts directly above and below the tumorous part, and 40cm above and below the center of the tumorous part to investigate characteristics of tumorous tissue and compare the tumorous tissue with normal ones anatomically in the qualitative and quantitative aspects of individual elements.

The small woods in size of matchstick taken from each sample disc were dipped into Schultze's solution, the concentrated nitric acid which was saturated with potassium chlorate(Berlyn and Miksche, 1976), for five days at room temperature and then heated mildly on an electrical heater until the wood samples were bleached white. After washing thoroughly in water, the

Fig. 1. Photographs of the tumorous tissue(A) formed after removal of a plastic band, 19mm wide, fastened around the stem for one year(B) and location of each sample disc(C) in the stem of *Ailanthus altissima* Swingle. DT : disc containing tumorous tissue 180cm above ground level ; DAD and DBD ; contiguous discs directly above and below DT ; DA40 and DB40 : discs 40cm above and below center of DT.

wood samples were macerated through gentle agitation by band.

The light microscopic observation and photographing of qualitative features were made from the prepared macerations by Olympus Model K microscope and Canon AE-1 Type camera attached to this microscope by Canon Photomicro Unit F. By random selection for the quantitative studies of wood elements, lengths of 100 wood fibers and 50 vessel elements of springwood and summerwood in each growth ring were measured from the macerations by the aid of optical bench comparator, Ernst Leitz GmbH. Wetzlar, Model TP 201. And radial and tangential diameters of 50 solitary pores and individual pores consisting of pore multiples on cross surface of springwood and summerwood, heights and widths of 100 rays on tangential surface, and ray densities, the numbers of rays per millimeter on cross surface, from 20 areas were determined on the permanent slides with the aid of the comparator as well. On the other hand, tangential and radial diameters of 50 libriform fibers were made on 4 cross sectional light micrographs by measuring with the same magnification's light micrograph of a stage micrometer. Growth ring widths were measured to the nearest tenth millimeter in crisscross direction of each sample disc.

In statistical analysis of the measured quantitative features on wood fibers, vessel elements, and rays, the means, standard deviations, and least significant differences at 0.05 and 0.01 probability level were determined by analysis of variance procedures from the LISA/HP3000 statistical package.

RESULTS AND DISCUSSION

Macroscopically the tumor wood in DT shows remarkably wider growth ring width and irregular outline of growth ring boundary(Fig. 2DT and Table 1). During the fastened period with a plastic band from mid-June 1985 to mid-June 1986, a dark line is formed in the intra-growth ring as a barrier zone which delimited the discolored wood from the normal-colored wood inwards and irregular-shaped growth ring boundary also appeared as that of tumor wood(Fig. 2 DT). In the same growth rings of DA40, DAD, DBD, and DB40, false ring-like zones corresponding to the barrier zone of DT are observed and inward radial spread of discoloration from the false ring-like zones takes place only in DA40 and DAD(Fig. 2).

Examinations of individual vessel elements and wood fibers isolated through maceration reveal

Table 1. Mean values for growth ring width measured in crisscross direction of each sample disc

Unit : mm

Growth ring number / Disc	Pith	1	2′*	2*	3	4
Disc 40cm above center of DT(DA40)	9.8	2.8	7.9	2.1	5.8	4.0
Contiguous disc directly above DT(DAD)	11.1	3.0	8.6	3.3	5.1	3.5
Disc containing tumor wood 180cm above ground(DT)	9.7	3.7	7.6	4.4	13.1**	4.0
Contiguous disc directly below DT(DBD)	11.2	3.3	7.9	2.3	6.7	4.1
Disc 40cm below center of DT(DB40)	14.4	3.0	7.7	1.4	5.3	4.4

*2′ and 2 denote proportions of the 2nd growth ring formed before and after barrier zone in DT and false ring-like zones corresponding to barrier zone of DT in DA40, DAD, DBD, and DB40, respectively.

**The 3rd ring of DT is tumor wood.

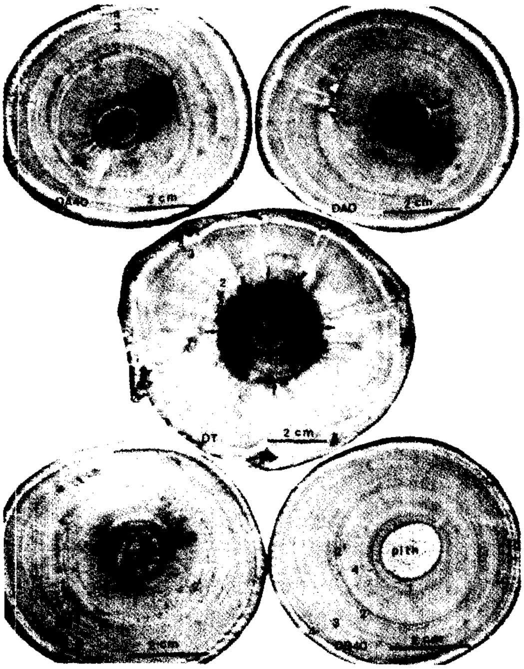

Fig. 2. Photographs of sample discs taken at the tumorous part(DT), contiguous parts directly above and below DT(DAD & DBD) and 40cm above and below the center of DT(DA40 & DB40). 2' and 2 denote proportions of the 2nd ring formed before and after barrier zone(↑) in DT and false ring-like zones, corresponding to barrier zone of DT, in DA40, DAD, DBD, and DB40. Inward discolored parts and the traumatic intercellular cavities(▲) also appeared. The 3rd ring of DT is tumor wood.

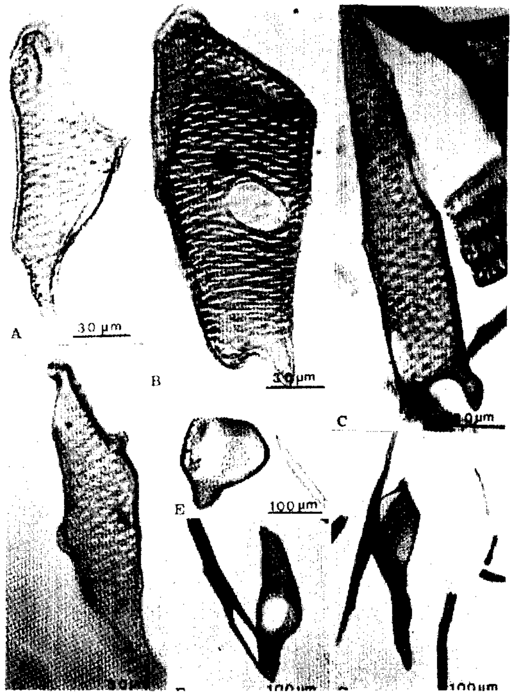

Fig. 3. The anomalous vessel elements. A and B, and E : the 3rd growth ring, tumor wood, and the 4th growth ring in DT, respectively ; C, D, F, and G : proportions of the 2nd growth rings formed after false ring-like zones in DAD, DB40, DA40, and DBD, respectively. Light micrographs.

important morphological alterations in the 3rd growth ring, i.e. tumor wood, proportion of the 2nd growth ring formed after barrier zone and before tumor wood, and the 4th growth ring formed after tumor wood in DT and proportions of the 2nd growth rings formed after false ring-like zones and before the 3rd growth rings, equivalent to proportion of the 2nd growth ring formed after barrier zone and before tumor wood in DT, in DA40, DAD, DBD, and DB40.

The vessel elements and wood fibers in tumor wood generally show irregular appearances(Fig. 3 A, B, and 4A, C). Tsoumis(1965) reported that tumor tracheids were seldom straight but usually curved, sometimes acquiring bizarre shapes, and some tumor strand tracheids might be very short and relatively wide, with the result that their ratio might even approach unity in the research on tumor wood of *Picea glauca*. Rickey *et al.* (1974) showed that the individual tracheids of tumor woods in *Picea sitchensis* were misshapen and generally curved. Recently, Tsoumis *et al.* (1988) observed that the macerated fibers of briarwood were usually irregular along their length.

In DT, on the other hand, the vessel elements in proportion of the 2nd growth ring formed after barrier zone and before tumor wood are more frequently misshapen(Fig. 4) but those in the 4th growth ring formed after tumor wood are less

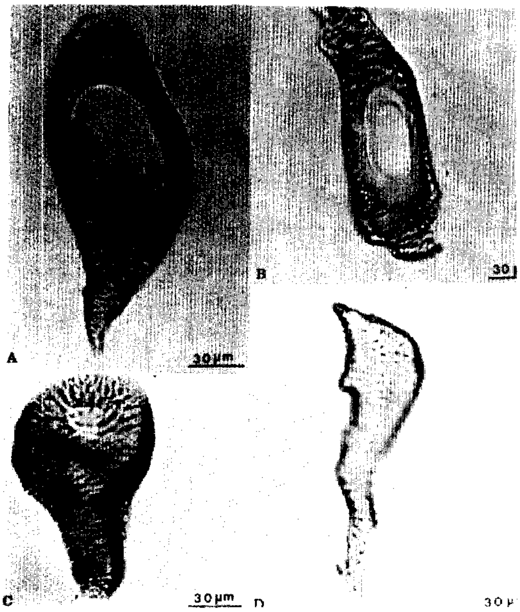

Fig. 4. The anomalous vessel elements. A, B, C, and D : proportion of the 2nd growth ring formed after barrier zone in DT. Light micrographs.

frequently irregular in shapes (Fig. 3E) than in tumor wood, the 3rd growth ring. However, the vessel elements showing misshapen appearance are rarely observed in proportion of the 2nd growth ring formed after false ring-like zone and before the 3rd growth ring, corresponding to proportion of the 2nd growth ring formed after barrier zone and before tumor wood in DT, in DA40, DAD, DBD, and DB40(Fig. 3C, D, F, and G).

Like the occurring tendency of misshapen vessel elements in DT, the anomalous wood fibers are observed more frequently in proportion of the 2nd growth ring formed after barrier zone and before the tumor wood but less frequently in the 4th growth ring formed after tumor wood(Fig. 5B, D, and E) compared with those of tumor wood, the 3rd growth ring(Fig. 5A and C). In each sample part DA40, DAD, DBD, and DB40, in addition, irregular wood fibers are generally identified in proportions of the 2nd growth rings formed after false ring-like zones and before the 3 rd growth rings, equivalent to proportion of the 2 nd growth ring formed after barrier zone and

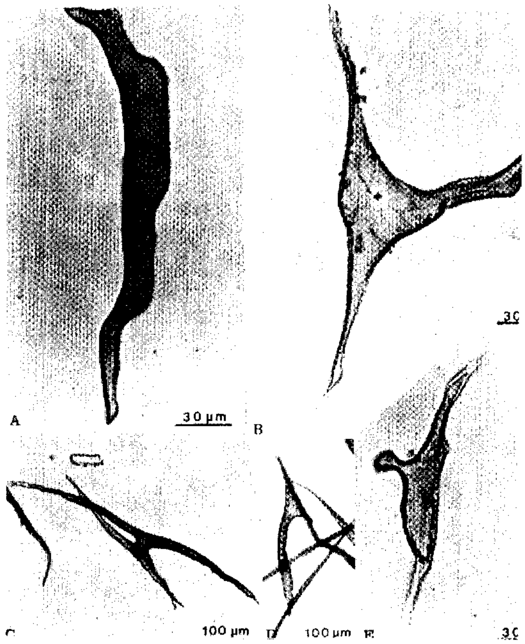

Fig. 5. The anomalous wood fibers. A and C, B and E, and D : the 3rd growth ring, i.e. tumor wood, proportion of the 2nd growth ring formed after barrier zone, and the 4th growth ring formed after tumor wood in DT, respectively. Light micrographs.

before tumor wood in DT, but rare occurrence of misshapen wood fibers are confirmed in the 3rd growth rings corresponing to tumor wood of DT (Fig. 6 and 7). Smith(1980) found vessel elements and fibers deviated from their normal structures in the wounded xylem of *Juglans nigra* and Lowerts et al. (1986) pointed out that individual vessel elements and fibers were often misshapen in wound-associated wood of *Liriodendron tulipifera*.

The individual vessel elements of highly variable structures observed in this study are lacking the tubular shape typical of this species(Fig. 8). The anomalous vessel elements develop lateral perforation plates(Fig. 3A, B, C, E, F, and 4A, B), imperforate tail(Fig. 4C), and lateral or longitudinal wall extensions(Fig. 3D, G, and 4D). The irregular wood fibers through macerations have bent shapes(Fig, 5A, 6C, and 7C) and bifid tips or wall projections (Fig. 5B, C, D, E, 6A, B,

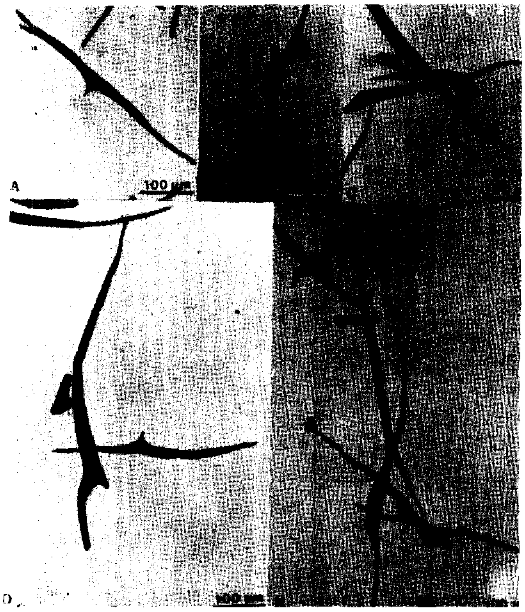

Fig. 6. The anomalous wood fibers. A and B, and C : proportion of the 2nd growth ring formed after false ring-like zone and the 3rd growth ring in DAD, respectively : D and E : the 3rd growth ring and proportion of the 2nd growth ring formed after false ring-like zone in DA40, respectively. Light micrographs.

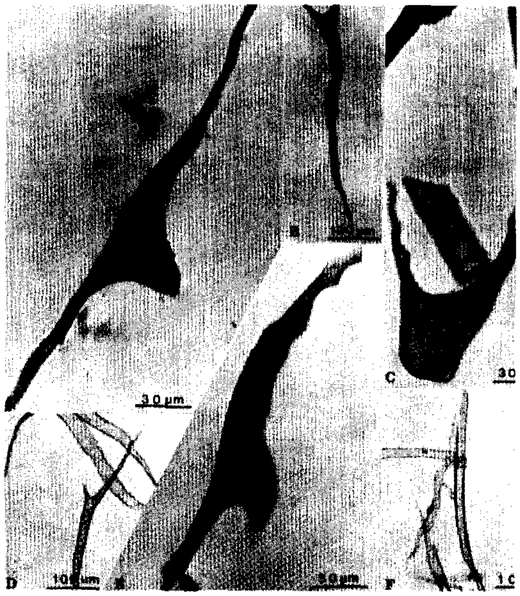

Fig. 7. The anomalous wood fibers. A and B and C, and D : proportion of the 2nd growth ring formed after false ring-like zone and the 3rd growth ring in DB40, respectively ; E and F : proportion of the 2nd growth ring formed after false ring-like zone and the 3rd growth ring in DBD, respectively. Light micrographs.

D, E, and 7A, B, D, E, F) when compared with normal wood fibers(Fig. 9). These anomalies in shapes of vessel elements and wood fibers seem to be caused by the alteration of cellular structures because the vessel elements and wood fibers are oriented perpendicular or near-perpendicular to tree's height direction. In addition, these misshapen wood fibers are rarely identified in inward parts formed immediately before barrier zone of DT(Fig. 10A and B) and false ring-like zones of DA40, DAD, DBD, and DB40(Fig. 10C).

In the studies on the quantitative features, the springwood vessel elements of the tumor wood, the 3rd growth ring, in DT are the shortest in lengths, and the same aged growth ring in DAD also shows somewhat reduced lengths differently from increasing trends of their lengths with the increasing age from the 2nd to 4th growth ring in DA40, DBD, and DB40(Fig. 11). And the tangential diameters of solitary pores and individual pores consisting of pore multiples in the first 1 to 3 rows of springwood pores exhibit somewhat smaller values differently from their radial diameters in the tumor wood compared with those of the same aged growth rings in DA40, DAD, DAB, and DB40 although the tangential and radial diameters appear to be smaller in the tumor wood, the 3rd growth ring, than those in the 2nd and 4th growth ring of DT(Fig. 12 and 13).

On the other hand, proportion of the 2nd growth ring formed after barrier zone in DT reveals the shortest summerwood vessel element lengths and the reduction in their lengths is larger in proportions of the 2nd growth rings formed after false ring-like zones of DA40 and DAD than in those of DB40 and DBD, with the increasing trends of their lengths with increasing distance from that of DT vertically(Fig. 14). Though the summerwood vessel element lengths are more or

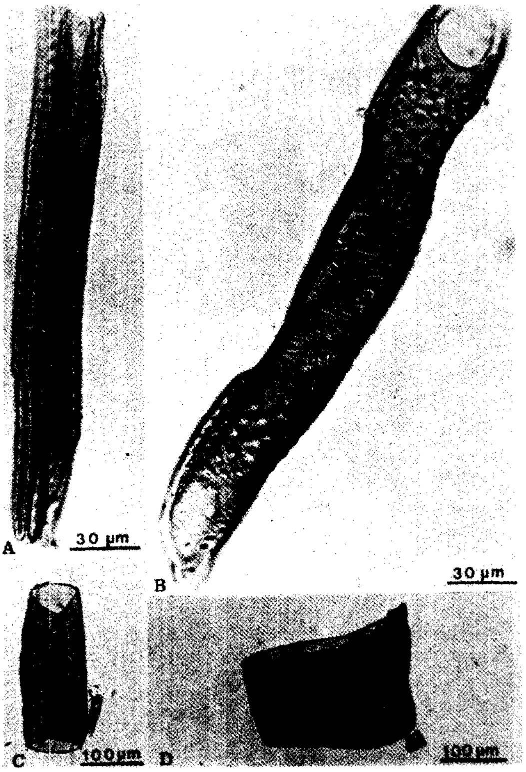

Fig. 8. The normal vessel elements. A : summerwood vessel elements in proportion of the 2nd growth ring formed before false ring-like zone of DBD ; B and C : summerwood vessel element of the 3rd growth ring and springwood vessel element of the 4th growth ring in DA40, respectively ; D : springwood vessel element in proportion of the 2nd growth ring formed before false ring-like zone of DAD. Light micrographs.

less shorter in tumor wood, the 3rd growth ring, of DT, they are not significantly shorter than those in the same aged growth rings of DA40, DAD, DBD, and DB40 but somewhat shorter compared with those in the 4th growth ring of DT (Fig. 14). In the tangential and radial diameters of solitary pores and individual pores consisting of pore multiples occurred in summerwoods, proportion of the 2nd growth ring formed after barrier zone in DT shows the largest radial diameters but does not show significantly larger than those in proportions of the 2nd growth rings formed after false ring-like zones in DA40 and DAD, whereas

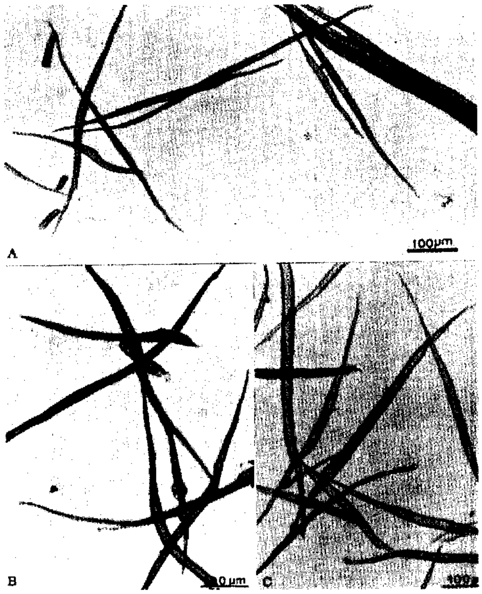

Fig. 9. The normal wood fibers. A : the 3rd growth ring of DA40 ; B : the 4th growth ring of DAD ; C : the 3rd growth ring of DBD. Light micrographs.

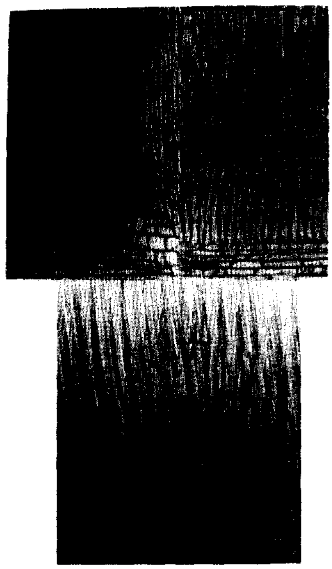

Fig. 10. Radial surfaces showing anomalous wood fibers(↑) in cellular structure. A and B : the inward part formed immediately before barrier zone in the 2nd growth ring of DT ; C : the inward part formed immediately before false ring-like zone in the 2nd growth ring of DA40. Light micrographs.

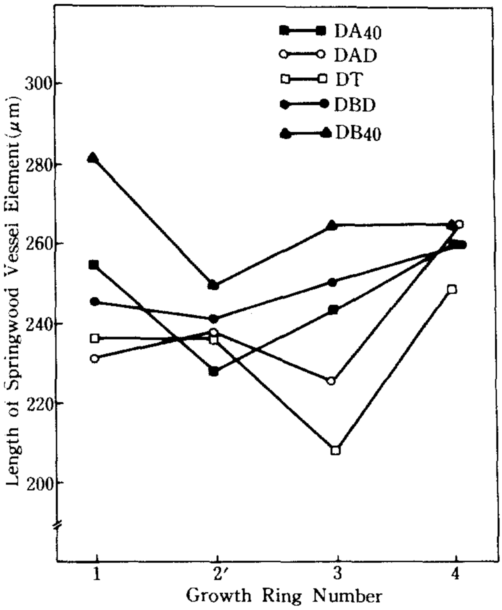

Fig. 11. Changes in length of springwood vessel element. See Fig. 1 and Table 1 as to the details of legend.

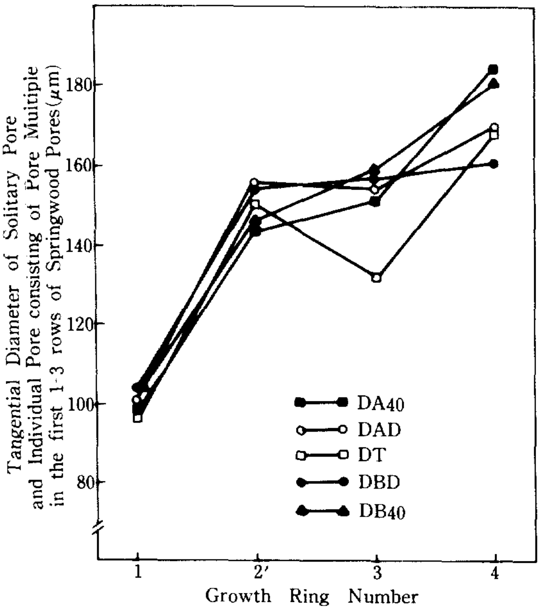

Fig. 12. Changes in tangential diameter of solitary pore and individual pore consisting of pore multiple in the first 1 to 3 rows of springwood pores. See Fig. 1 and Table 1 as to the details of legend.

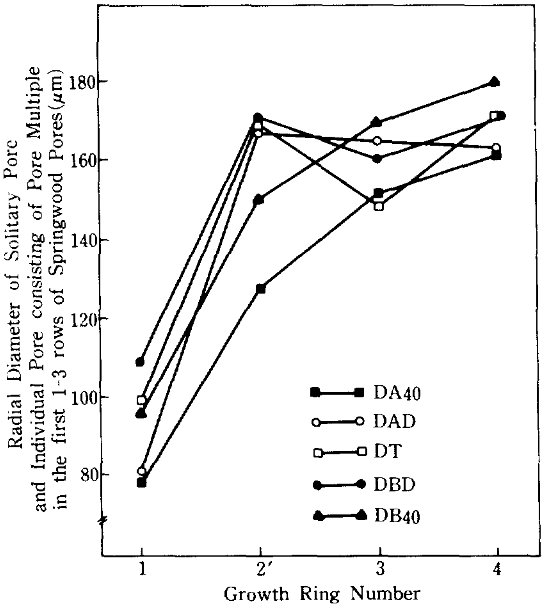

Fig. 13. Changes in radial diameter of solitary pore and individual pore consisting of pore multiple in the first 1 to 3 rows of springwood pores. See Fig. 1 and Table 1 as to the details of legend.

proportion of the 2nd growth ring formed after barrier zone in DT shows the smallest tangential diameters but does not show significantly smaller values than those in proportions of the 2nd growth rings formed after false ring-like zones in DBD and DB40(Fig. 15).

However, their radial and tangential diameters in proportion of the 2nd growth ring formed after barrier zone in DT disclose significantly larger and smaller values than those in proportions of the 2nd growth rings formed after false ring-like zones in DBD and DB40, and DA40 and DAD, respectively, and they also show the respective tendencies to be smaller and larger from their large radial diameters and small tangential diameters, thus forming somewhat isodiametric pores in the tumor wood, the 3rd growth ring, in DT(Fig. 15).

Proportion of the 2nd growth ring formed after barrier zone in DT exhibits the shortest wood fiber lengths and the reduction in wood fiber lengths is also confirmed in proportion of the 2nd

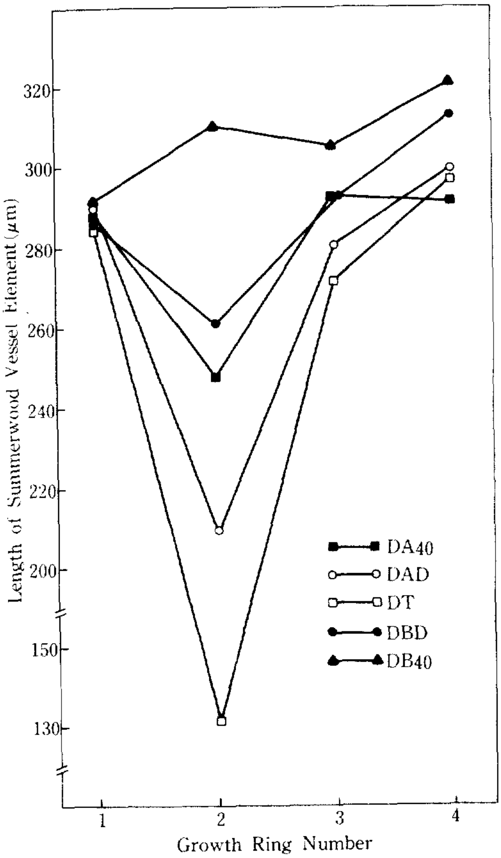

Fig. 14. Changes in length of summerwood vessel element. See Fig. 1 and Table 1 as to the details of legend.

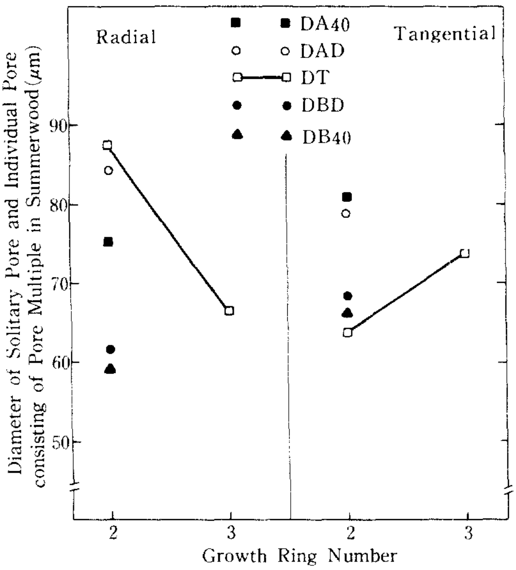

Fig. 15. Changes in radial and tangential diameters of solitary pore and individual pore consisting of pore multiple in summerwood. See Fig. 1 and Table 1 as to the details of legend.

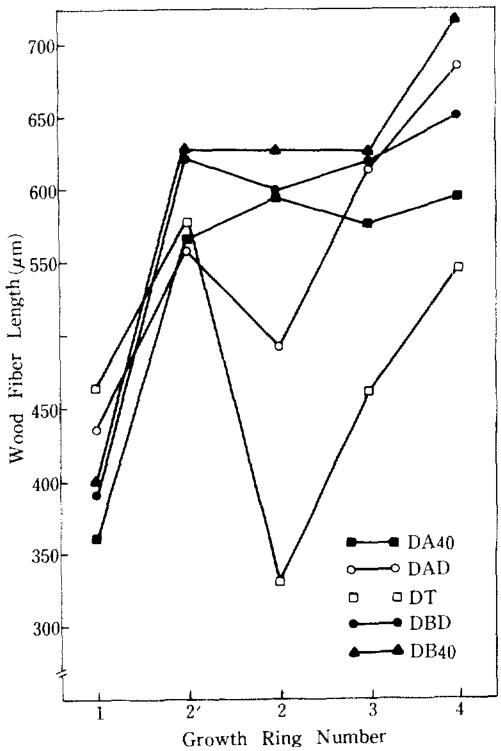

Fig. 16. Changes in length of wood fiber. See Fig. 1 and Table 1 as to the details of legend.

growth ring formed after false ring-like zone in DAD. In addition, the wood fibers show the trend of increase in lengths with increasing age from proportion of the 2nd growth ring formed after barrier zone to the 4th growth ring in DT and the tumor wood, i.e. the 3rd growth ring, and the 4 th growth ring in DT reveal shorter wood fiber lengths compared with those of the same aged growth rings in DA40, DAD, DBD, and DB40(Fig. 16). On the other hand, the radial and tangential diameters of libriform fibers in proportion of the 2nd growth ring formed after barrier zone in DT are the smallest but appear not to be significantly smaller than those in proportions of the 2nd growth rings formed after false ring-like zones in DAD and DBD and appear to be significantly smaller than those in proportions of

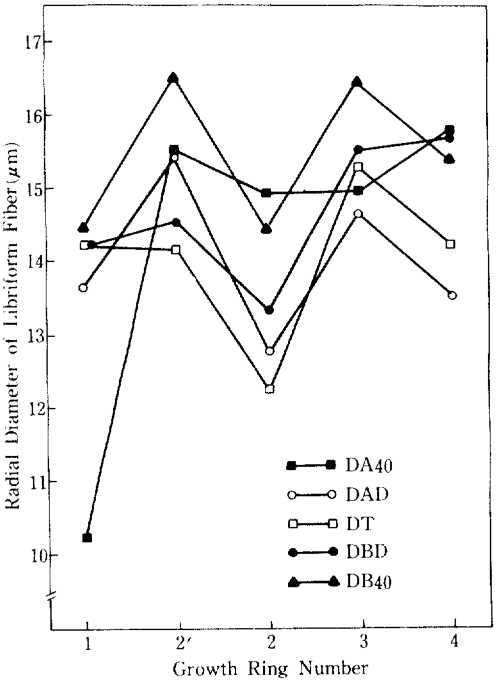

Fig. 17. Changes in radial diameter of libriform fiber. See Fig. 1 and Table 1 as to the details of legend.

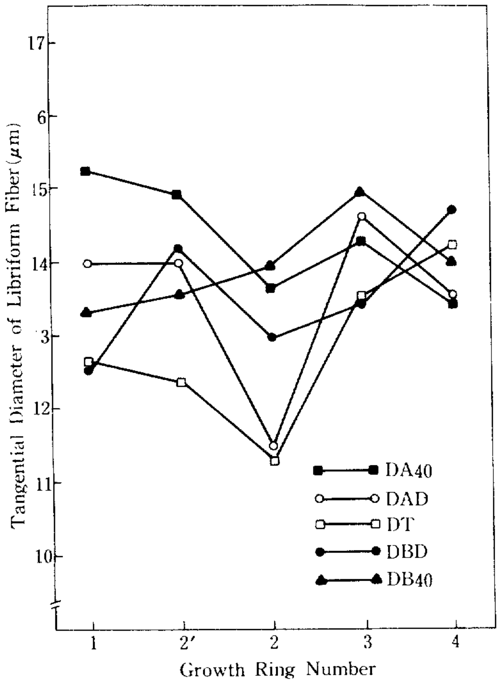

Fig. 18. Changes in tangential diameter of libriform fiber. See Fig. 1 and Table 1 as to the details of legend.

the 2nd growth rings formed after false ring-like zones in DA40 and DB40. However, the libriform fibers in the tumor wood, the 3rd growth ring, of DT do not significantly differ in the radial and tangential diameters compared with those in the same aged rings of DA40, DAD, DBD, and DB40(Fig. 17 and 18), which concurred with White (1958b) who noted in the report concerning tumor woods on *Picea glauca* that the cell size of tumor wood was not sufficiently different from that of adjacent normal wood to account for the massive character of the external growth and this overgrowth arose from differencies not in cell size but in cell number. The similar results that tumor xylem cells were usually not much larger than those in healthy tissue but 1.1 to 10.0 times more cells were produced along a given radius in a tumor wood than nearby outside the tumor wood were observed in the studies on tumor woods of *Pinus contorta*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Abies lasiocarpa*, and *Picea engelmannii* by Peterson(1961). Tsoumis(1965) found the tracheids of tumor wood on *Picea glauca* to be shorter in length and wider in width than those of normal wood and Rickey *et al*.(1974) reported the short longitudinal tracheids of tumor wood in *Picea sitchensis*. Recently, Tsoumis et al.(1988) suggested that tumor fibers were shorter than those of the stem and root in the research on briarwood, the tumor wood of *Erica arborea* developed between root and stem.

In a research on mechanically injured *Juglans nigra* trees, Smith(1980) noted that vessel elements and fibers in the abnormal wood zone formed following injury were significantly shorter than those in normal wood and vessel elements in the abnormal wood zone were also significantly greater in diameter than those in normal wood zone although fiber diameters did not differ significantly between locations, and suggested that the reduction in vessel element and fiber lengths in the abnormal wood zone might be related to the similarly reduced fusiform initial lengths in the vascular cambium. Bauch *et al*.(1980) found that the average size of a single vessel element decreased greatly in the growth ring immediately after wounding and the fibers produced after wounding were significantly shorter than those in the growth rings formed before wounding in a study on the wounded xylem of *Acer rubrum* and *Betula papyrifera*, and Rademacher *et al*.(1984) reported that the vessel elements were smaller in length and diameter and the fibers were shorter in the wounded xylems of *Acer saccharum*, *Betula alleghaniensis*, and *Fagus grandifolia*. Yamanaka (1985) showed that the earlywood tracheids produced after the abnormal wood formation in the swollen stem of *Chamaecyparis obtusa* were shorter than those in the inner rings and the similarly aged rings of normal stem. Recently, Lowert *et al*.(1986) found that length and diameter of vessel element and fiber length were significantly lower in wound-associated wood of *Liriodendron tulipifera*.

The heights and widths of rays in proportion of the 2nd growth ring formed after barrier zone in DT are sufficiently taller and wider than those in proportions of the 2nd growth rings formed after false ring-like zones in DA40, DBD, and DB40 but are not significantly taller and wider than those in proportion of the 2nd growth ring formed after false ring-like zone in DAD. And the tumor wood, the 3rd growth ring, in DT reveals significantly taller heights and wider widths of rays than those in the same aged growth rings in DA40, DAD, DBD, and DB40 but their differences are not confirmed among the 4th growth ring of each sample part. On the other hand, the ray widths in proportions of the 2nd growth rings formed after barrier zone in DT and false ring-like zones in DA40, DAD, DBD, and DB40 are remarkably wider than those in the respective proportions of the 2nd growth rings formed before barrier zone and false ring-like zones, especially in DT and DAD, whereas only proportion of the 2nd growth ring formed after barrier zone in DT shows the increased ray heights compared with that formed before barrier zone. In DT, the tumor wood, the 3rd growth ring, exhibits signigicantly taller ray heights but does not show significantly wider ray widths, though the ray widths increase in some degree, compared with proportion of the 2nd growth ring formed after barrier zone. However, both the ray widths and heights greatly decrease in the 4th growth ring compared with the tumor wood, the 3 rd growth ring, in DT(Fig. 19 and 20).

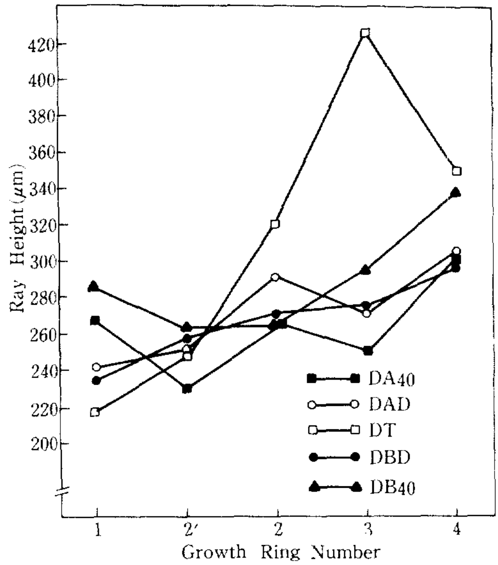

Fig. 19. Changes in ray height. See Fig. 1 and Table 1 as to the details of legend.

The ray densities, the numbers of rays per millimeter on cross surface, in proportions of the 2nd growth rings formed after barrier zone of DT and false ring-like zones of DAD and DBD are significantly greater than those in the respective proportions of the 2nd growth rings formed before barrier zone and false ring-like zones, differently from the decreasing trends of ray densities with the increasing age from proportions of the 2nd growth rings formed before false ring-like zones to the 3rd growth rings in DA40 and DB40. The ray densities in proportion of the 2nd growth ring formed after barrier zone in DT, though they appear to be the greatest, are not significantly greater than those in proportion of the 2nd growth ring formed after false ring-like zone in DAD but significantly greater than those in proportions of the 2nd growth rings formed after false ring-like

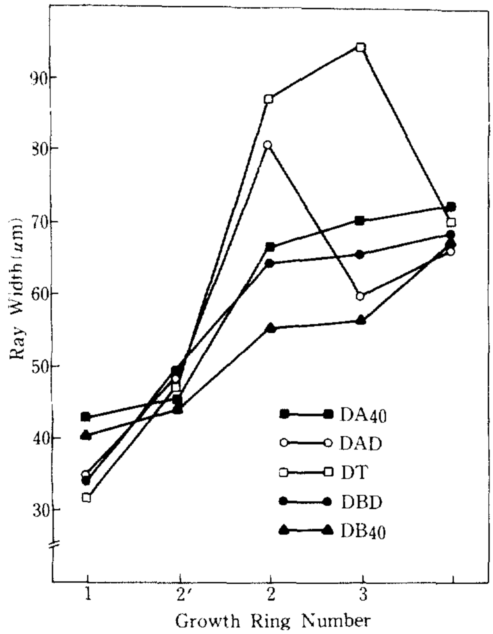

Fig. 20. Changes in ray width. See Fig. 1 and Table 1 as to the details of legend.

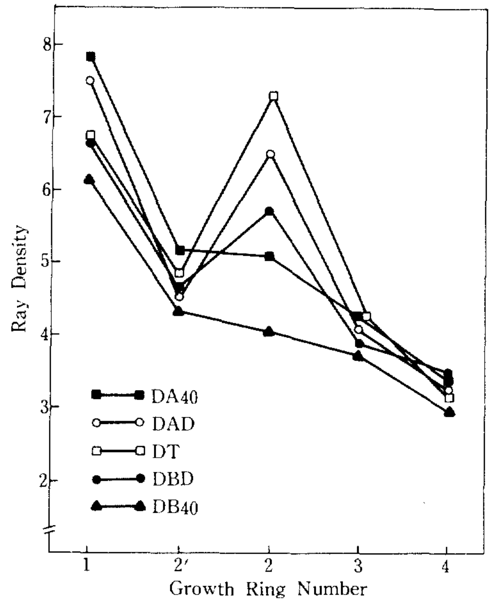

Fig. 21. Changes in ray density. See Fig. 1 and Table 1 as to the details of legend.

zones in DA40, DBD, and DB40. However, the tumor wood, the 3rd growth ring, in DT does not show greater ray densities compared with those in DA40, DAD, DBD, and DB40(Fig.21). The remarkable increases of ray heights and widths observed in proportion of the 2nd growth ring formed after barrier zone and tumor wood, the 3rd growth ring, in DT and in proportion of the 2nd growth ring formed after false ring-like zone in DAD, as well as the greatly increased ray densities in proportions of the 2nd growth rings formed after barrier zone in DT and false ring-like zone in DAD, seem to contribute to the increases in ray volumes.

Peterson(1961) reported that tumor xylems contained normal percentages of ray parenchymas in a research on the tumor woods of *Pinus contorta*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Abies lasiocarpa*, and *Picea engelmannii* and Rickey *et al*.(1974) found that the tumor wood generally had larger ray cells than those of normal wood in *Picea sitchensis*.

Bauch *et al*.(1980) pointed out that the ray portions greatly increased, the individual ray cells were larger, and new rays developed after wounding of the xylems in *Acer rubrum* and *Betula papyrifera*, but Smith(1980) noted that there were no apparent structural changes taking place in the ray system between normal wood and abnormal wood zone tissues and ray size, shape, and distribution did not appear altered in the abnormal wood zone in the study on mechanically injured trees of *Juglans nigra*. The increased ray widths after wounding were demonstrated in *Acer saccharum*, *Betula alleghaniensis*, and *Fagus grandifolia* by Rademacher *et al*.(1984). Lowerts *et al*.(1986) showed that ray height and width increased and the individual ray cells were larger in diameter and wall thickness, but the maximum ray volume occurred the second year after wounding though the maximum ray density occurred the first year after wounding in the wound-associated wood of *Liriodendron tulipifera*.

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