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# A COMPARATIVE STUDY OF SOME TUMOROUS AND NORMAL HARDWOOD KRAFT PULP PROPERTIES

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## ABSTRACT

In this study, how tumor formation in *Quercus robur* subsp. *robur* L., *Acer campestre* L., and *Carpinus betulus* L affects the properties of kraft pulp and paper were investigated. In addition, chemical composition and fiber characteristics such as fiber length and fiber width of both normal wood and tumorous wood *Acer campestre* L. and *Carpinus betulus* L. were compared. Tumorous wood was occurred as a result of topping stress. Experiments showed that tumor formations of these species were negatively affected physical properties of handsheets except for tear index and stretch in *Q. robur.* Fiber properties of tumorous woods were significantly different from than those of normal woods. Tumorous fibers and vessel elements were short and abnormal shaped. Moreover, chemical composition of normal woods was found in different tumorous woods.

KEY WORDS: topping stress, hardwood, tumorous wood, kraft paper, physical and optical properties.

## INTRODUCTION

Tumorous wood, a swelling overgrowth tissue, may be formed in living trees when the cambium in the growing season is wounded or its normal activity is influenced by several causes (Eom 1991). When the cambium is injured during the vegetation season or its normal activity is modified, a tree may form various kinds of abnormal tissue such as tumor wood, burl, etc. These abnormal formations occur on the stem, branch, root and even between root and stem, and a tumor wood may be entirely on one side of a branch or stem, or it may completely surround the branch. Tumorous wood can be developed either by an increase in the rate of formation of new cells or by prolongation of growth period. Up till now, the causes of tumor formation have not been completely identified, but hypotheses suggesting genetic instability, cambial injury by insects and bacteria, sea water spray, or unregulated synthesis of auxin and cytokinin have all been proposed and none of these agencies has been known ever to develop the tumorous wood alone (White et al. 1954a,b, White et al. 1967, White 1958a,b, Peterson 1961, Tsoumis 1965, DeTorok 1967, Rickey et al. 1974, Kramer and Kozlowski 1979, Tsoumis et al. 1988).

In earlier studies related to tumorous wood anatomy has largely been confined to softwoods (Eom 1991). Some studies were made on *Picea glauca* (White 1954b, White 1958a,b, White et al. 1967), *Pinus contorta*, *Pinus flexilis*, *Pseudotsuga menziesii*, *Abies lasiocarpa* and *Picea engelmannii* (Peterson, 1961). Some studies were made on anatomy of hardwood tumorous tissues such as *Erica arborea* (Tsoumis et al. 1988), *Ailanthus altissima* (Eom and Lee 1989). Wood anatomy, fiber morphology and chemical properties of *Quercus robur* L. tumorous and normal wood have been reported in our previously study (Gülsoy et al. 2005). A study was made on the chemical structure and kraft paper properties of tumorous *Picea sitchensis* (Rickey et al. 1974).

The purpose of this study is to determine the effect of tumorous wood of some hardwoods (*Quercus robur* L. subsp *robur*, *Acer campestre* L., and *Carpinus betulus* L.) on physical and optical properties of kraft papers, as well as to determine chemical composition and fiber properties of *Acer campestre* L., and *Carpinus betulus* L. tumorous woods.

## MATERIAL AND METHODS

### Wood Specimens

Tumorous wood specimens were obtained from tumorous trees of *Quercus robur* L. subsp. *robur*, *Acer campestre* L., and *Carpinus betulus* L. growing in Bartın province of Turkey. Tumorous trees are decimated in every 5-10 years to use as fuel wood. Some properties of tumor formation of the tumorous trees are given in Tab. 1. For comparison, normal wood samples were also obtained from the opposite side of the tumorous wood specimen in the same tumorous trees.

*Tab.1: Some properties of tumor formation on the affected trees*

| | ***Quercus robur* L. subsp. *robur*** | ***Acer campestre* L.** | ***Carpinus betulus* L.** |
|---|---|---|---|
| Height from ground level of tumor formation (cm) | 280 | 135 | 155 |
| Height of tumor formation (cm) | 30 | 35 | 30 |
| Width of tumor formation (cm) | 24 | 25 | 20 |
| Age of tree | 112 | 97 | 131 |

### Chemical Analyses of Woods

Preparation of samples, lignin content, solubility values in 1% NaOH, cold water, hot water, and ethanol were determined according to TAPPI standard methods. Cellulose and holocellulose content were determined according to Kürschner-Hoffer method (Kürschner. and Hoffer 1929) and Wise's chlorite method (Wise et al. 1946), respectively. Air-dry specific gravity of tumorous and normal woods was determined according to ISO 3131 (1975) standard test method.

### Fiber Morphology

Small wood pieces as the size of matchsticks were taken and each sample was dipped in Schultze's solution for a week at room temperature. Softened and bleached wood samples were agitated gently to disintegrate individual fibers (Berlyn and Miksche 1976). Individual fibers were dehydrated with ethyl alcohol and stored in glycerine after staining with safranin. Lengths of 50 randomly selected fibers and vessel elements, widths of 25 fibers and fiber lumen were measured in macerated fibers. Vessel element length measured including tail and widths were measured at the widest part of the macerated cells (Carlquist 1988). Measurements were made according to IAWA Committee Nomenclature (1964).

## Pulping

Tumorous and normal woods were cut to about 2.5-1.5-0.5 cm in size for pulping. The kraft cooking conditions for tumorous and normal woods of all species were: 16% active alkali concentration as $Na_2O$, 20% sulfidity, 4:1 liquor/wood ratio, 165 °C cooking temperature, 90 min to cooking temperature and 90 min at cooking temperature. After digestion, pulps were washed free of black liquor. The pulp yield was determined as percentage of oven-dry raw materials. Kappa number and freeness of pulps were determined according to relevant TAPPI Standard Methods.

## Evaluation of Pulps

After cooking, pulps were beaten to 50±3 °SR in a Valley-type beater. Then, handsheets were made by Rapid-Köthen sheet former. The handsheets were conditioned according to relevant TAPPI Standard Method. Physical (TAPPI) and optical (ISO) properties of handsheets were made in accordance with relevant Standard Methods.

# RESULTS AND DISCUSSION

## Chemical Composition of Tumorous and Normal Woods

The effects of tumor formation on chemical composition and specific gravity of *A. campestre,* and *C. betulus* are given in Tab. 2. As can be seen from Tab. 2, the holocellulose content difference between tumorous and normal wood of *A. campestre* was not statistically significant. Specific gravity of tumorous wood in *A. campestre* was higher than that of normal wood. Lignin content of tumorous wood in *A. campestre* was found 5.2% higher. This agrees with observation on *Populus tremuloides* gall wood (Crane et al. 1995). Cellulose content of tumorous wood was found to be 3.7% lower. Solubility ratios such as cold water, hot water, 1% NaOH, and ethanol of tumorous wood in *A. campestre* were found lower than those of normal wood 0.9%, 1.3%, 4.2%, and 2%, respectively.

The differences of cellulose and lignin contents of tumorous and normal wood in *C. betulus* were not found statistically significant. Whereas, holocellulose content of tumorous wood in *C. betulus* was 2.6% higher. Specific gravity of tumorous wood was lower than that of normal wood. Solubility ratios such as cold water, hot water, 1% NaOH, and ethanol of tumorous wood of *C. betulus* were found lower than those of normal wood 1.8%, 3%, 1.1%, and 2.5%, respectively. On the contrary, solubility values of *Quercus robur* tumorous wood were higher (Gülsoy et al. 2005).

According to chemical analysis results, hemicellulose content of tumorous wood in *A. campestre,* and *C. betulus* was higher than those of normal woods. This agrees with observation on *Picea sitchensis* tumorous wood (Rickey et al. 1974). Solubility ratios (such as cold water, hot water, 1% NaOH, and ethanol-benzene) of tumorous wood in *A. campestre,* and *C. betulus* were lower than those of normal wood. Besides, *A. campestre* and *C. betulus* tumorous wood had significantly high specific gravity. Similar results were found on *Michelia champaca* (Das 1994) and *Erica arborea* (Tsoumis et al. 1988).

*Tab. 2: Chemical composition and specific gravity of tumorous and normal woods*

| Species | HC (%) | CC (%) | LC (%) | HWS (%) | CWS (%) | ES (%) | 1%NaOH (%) | SG ($g/cm^3$) |
|---|---|---|---|---|---|---|---|---|
| Normal *A. campestre* | 75.2±0.7a | 50.9±0.7a | 23.8±0.5a | 5.7±0.1a | 3.4±0.3a | 4.1±0.1a | 16.7±0.1a | 0.59±0.01a |
| Tumorous *A. campestre* | 74.0±1.2a | 47.2±0.6b | 29.0±0.1b | 4.4±0.1b | 2.5±0.2b | 2.1±0.1b | 12.5±0.3b | 0.79±0.01b |
| Normal *C. betulus* | 79.6±0.1a | 49.6±0.7a | 18.9±0.3a | 6.3±0.4a | 4.6±0.1a | 4.9±0.1a | 19.7±0.6a | 0.72±0.03a |
| Tumorous *C. betulus* | 82.2±0.1b | 50.6±0.6a | 18.4±0.1a | 3.3±0.1b | 2.8±0.1b | 2.4±0.1b | 18.6±0.3b | 0.79±0.02b |

*± Standard Deviation,*
*a: Within a column, means bearing same letter are not significantly different ($P<0.05$)*
*HC: Holocellulose Content, CC: Cellulose Content, LC: Lignin Content, HWS: Hot Water Solubility, CWS: Cold Water Solubility, ES: Ethanol Solubility, 1% NaOH: 1 % NaOH Solubility, SG: Specific Gravity*

## Fiber Properties of Tumorous and Normal Woods

Fiber properties of tumorous and normal woods of *A. campestre,* and *C. betulus* are given in Tab. 3. As can be seen from Tab. 3, fiber properties of affected trees were significantly changed. Fiber length and vessel element length of tumorous woods were significantly shorter than those of normal wood. This agrees with the previous studies on *Picea sitchensis* (Rickey et al. 1974), on *Juglans nigra* (Smith 1980), on *Liriodendron tulipifera* (Lowerts et al. 1986), on *Erica arborea* (Tsoumis et al. 1988), on *Ailanthus altissima* Swingle (Eom and Lee 1989), on *Pinus densiflora* (Eom and Chung 1994), on *Populus tremuloides* (Crane et al. 1995) and on *Quercus robur* (Gülsoy et al. 2005). As a result of statistical analyses, fiber width differences between normal and tumorous wood of *C. betulus* were not found significant. But, *A. campestre* tumorous wood had narrow fibers. On the other hand, double wall thickness differences between normal and tumorous wood of *C. betulus* and *A. campestre* were not statistically significant. On the contrary, double wall thickness of *Q. robur* tumorous wood was larger (Gülsoy et al. 2005). However lumen thickness of *A. campestre* was narrower than that normal wood. On the contrary, lumen thickness of *C. betulus* was larger than that of normal wood. These results clearly show that the effect of tumor formation on fiber properties was different in each species.

*Tab. 3: Fiber properties of tumorous and normal woods*

| Species | FL (µm) | VEL (µm) | FW (µm) | DWT (µm) | FLT (µm) |
|---|---|---|---|---|---|
| Normal *A. campestre* | 581.6± 96 a | 322.0±38 a | 25.0±3.3 a | 8.7±1.8 a | 16.3±3.1 a |
| Tumorous *A. campestre* | 406.3±73 b | 160.5±40 b | 20.6±3.7 b | 9.6±2.5 a | 11.0±2.7 b |
| Normal *C. betulus* | 1235.1±214 a | 708.0±113 a | 22.1±4.1 a | 11.1±2.1 a | 11.0±3.7 a |
| Tumorous *C. betulus* | 1108.2±193 b | 588.9±170 b | 25.3±5.1 a | 9.6±2.6 a | 15.4±4.1 b |

*± Standard Deviation*
*a: Within a column, means bearing same letter are not significantly different ($P<0.05$)*
*FL: Fiber Length, VEL: Vessel Element Length, FW: Fiber Width, DWT: Double Wall Thickness, FLT: Fiber Lumen Thickness*

Fibers of tumorous wood were abnormal shaped (Fig. 1-3, 6-9, 10, 11). These abnormal formations agree with the observations on *Ailanthus altissima* Swingle (Eom and Lee 1989), on *Picea glauca* (Tsoumis 1965), on *Picea sitchensis* (Rickey et al. 1974), on *Erica arborea* (Tsoumis et al. 1988), *Liriodendron tulipifera* (Lowerts et al. 1986). On the other hand, *C. betulus* tumorous wood had gelatinous fibers (Fig. 9). Gelatinous fibers were determined in *Ailanthus altissima* tumorous wood (Eom and Lee 1989) and in *Juglans nigra* wounded wood (Smith 1980). Tumorous wood vessel elements were also abnormal shaped (Fig. 4, 5, 12). Abnormal shaped vessel elements also observed in *Ailanthus altissima* tumorous wood (Eom and Lee 1989).

Fibers and vessel elements of tumorous woods can be seen from Fig. 1 through 12. Tumorous *A. campestre* wood had abnormal shaped fiber (Fig. 2) and vessel element (Fig. 4), hooked (Fig. 1) and forked (Fig. 3) fibers. Abnormal shaped fibers (Fig. 6-8) and vessel element (Fig. 5) were appeared in tumorous *Q. robur* wood. Tumorous *C. betulus* wood had abnormal shaped fibers (Fig. 10, 11), vessel element (Fig. 12), and gelatinous fiber (Fig. 9).

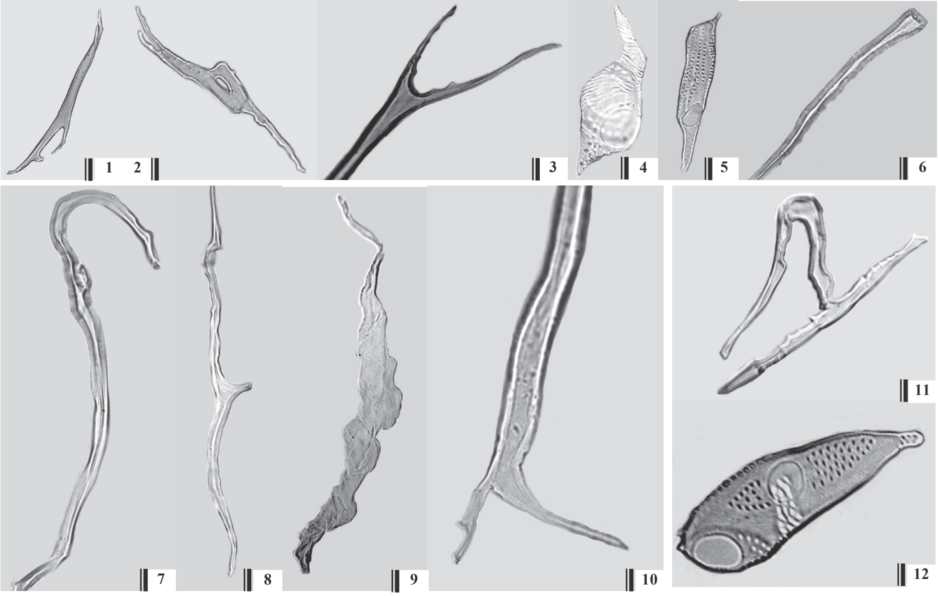

*Fig. 1-4: Fibers and vessel element of tumorous A. campestre. Hooked fiber (Fig. 1), abnormal shaped fiber (Fig. 2), forked fiber (Fig. 3), and abnormal shaped vessel element (Fig. 4)*
*Fig. 5-8: Fibers and vessel element of tumorous Q. robur. Abnormal shaped fibers (Fig. 6-8) and vessel element (Fig. 5)*
*Fig. 9-12: Fibers and vessel element of tumorous C. betulus. Gelatinous fiber (Fig. 9), forked fiber (Fig. 10), abnormal shaped fiber (Fig. 11) and vessel element (Fig. 12), Scale bars: 25µm in Fig 1-7, 10-12. 50µm in Fig 8-9*

## Kraft Pulp and Handsheet Properties of Tumorous and Normal Woods

Kraft pulp and handsheet properties of tumorous and normal woods of *Q. robur, A. campestre,* and *C. betulus* are given in Tab. 4. As seen in Tab. 4, pulp of tumorous wood of *Q. robur* and *C.*

*betulus* had high yield compared to normal wood. On the contrary, pulp of tumorous wood of *A. campestre* had lower yield. The beating response of tumorous wood fibers in *C. betulus* was better than that of normal wood. However, the beating response of normal wood fibers in *Q. robur* and *A. campestre* was better than those of tumorous wood. The differences in response to beating depend on fiber morphologies of the species.

*Tab. 4: Kraft pulp and handsheets properties of tumorous and normal woods of Q. robur, A. campestre, and C. betulus*

| **Properties** | **Normal** *Q. robur* | **Tumorous** *Q. robur* | **Normal** *A. campestre* | **Tumorous** *A. campestre* | **Normal** *C. betulus* | **Tumorous** *C. betulus* |
|---|---|---|---|---|---|---|
| Kappa no | 49.4 | 47.8 | 31.3 | 38.9 | 28.4 | 27.9 |
| Pulp yield (%) | 27.5 | 32.7 | 45.3 | 42.9 | 48.4 | 52.5 |
| Reject ratio (%) | 18.7 | 10 | 0.5 | 2.4 | 1.2 | 1.4 |
| Freeness (ºSR) | 53 | 50 | 53 | 53 | 53 | 52 |
| Beating time (min) | 22 | 30 | 30 | 46 | 28 | 23 |
| Bulk | 1.48 | 1.55 | 1.41 | 1.57 | 1.45 | 1.36 |
| Tensile Index (N.m/g) | 61.4±2.1a | 56.1±1.2b | 77.4±8.8a | 64.2±8.2a | 77.5±1.8a | 72.8±0.2b |
| Stretch (%) | 1.8±0.1a | 2.0±0.2b | 2.3±0.2a | 2.4±0.1a | 2.1±0.1a | 1.8±0.2b |
| Breaking length (km) | 7.2±0.4a | 6.0±0.6b | 7.3±0.7a | 6.5±0.7b | 8.8±0.5a | 7.7±0.8b |
| Burst Index (kPa.m$^2$/g) | 4.2±0.3a | 3.6±0,1b | 4.8±0.1a | 4.0±0.2b | 5.9±0.1a | 4.9±0.2b |
| Tear Index (mN.m$^2$/g) | 3.6±0.8a | 4.9±1.6b | 4.3±0.7a | 3.8±0.7a | 5.2±0.4a | 5.1±1.0a |
| Double fold (no.) | 150.3±20.8 a | 120.8±16.0 b | 452.2±27.0 a | 241.3±43.4 b | 452.6±57.7 a | 286.3±27.9 b |
| TEA (j/m$^2$) | 61.6±9.0a | 60.0±9,4a | 86.8±12.6a | 94.9±7.1a | 87.4±7.1a | 71.3±14.1b |
| Air permeability (ml/min) | 47.5±7.2a | 154±14.3b | 91.5±7.1a | 173±9.5 b | 23±2.6 a | 30±2.4 b |
| Smoothness (ml/min) | 463.3±26.5 a | 416.7±29.4 b | 396.6±23.4 a | 356.7±15.1 b | 470.0±10.9 a | 396.7±15.1 b |
| Thickness (µm) | 103.6±4.7a | 108.4±1.3b | 98.7±3.8 a | 109.8±1.7 b | 101.8±3.9 a | 95.4±2.1 b |
| Opacity (% ISO) | 98.9±0.3a | 99.2±0,3a | 99.4±0.2a | 99.7±0.1a | 98.9±1.3a | 98.8±1.2a |
| Brightness (% ISO) | 11.4±0.1a | 10.8±0,2a | 23.6±0.3a | 22.0±0.1b | 14.6±0.5a | 16.7±0.4b |

± *Standard Deviation*
*a: Within a line, means bearing same letter are not significantly different (P<0.05)*

Handsheets obtained from kraft pulps of *Q. robur*, *A. campestre* and, *C. betulus* tumorous wood had lower strength properties compared to handsheets from normal wood except for stretch and tear strength of tumorous *Q. robur* handsheets. The surface of tumorous wood handsheets was smoother and higher air permeability values. Hence, tumorous wood handsheets had loose structure considering normal wood handsheets. Besides, bulk values of *Q. robur* and *A. campestre* tumorous wood handsheets were determined higher. Differences in optical properties between *Q. robur* tumorous and normal wood handsheets were not statistically significant. *A. campestre* normal wood handsheets had higher brightness values. Brightness of *C. betulus* tumorous wood handsheets was slightly higher than that of normal wood handsheets. Opacity of handsheets was not changed after tumor formation. Handsheets prepared from kraft pulp of tumor-affected *Picea sitchensis* wood (Rickey et al. 1974) had lower burst, tear, tensile, and opacity but higher in fold, shrinkage, density, and air resistance compared to pulp from normal wood.

## CONCLUSIONS

Tumor wood is an abnormal formation on trees and has different structure considering normal wood. Kraft handsheet properties, fiber morphology, and chemical composition differences between tumorous wood and normal wood were investigated. The results clearly showed that tumor formation was negatively affected the strength properties of handsheets. Optical properties of handsheets were not significantly changed by tumor formation. The fiber morphology and chemical composition of tumorous woods were found statistically different from those of normal woods. This paper might help to clarify the effect of tumor formation on kraft handsheet properties, fiber morphology, and wood chemical composition.

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