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THE CROSS-SECTION VARIATIONS IN TURKISH PINE (*Pinus brutia* TEN.) NEEDLES AS AN INDICATOR OF ATMOSPHERIC POLLUTION: GÖKOVA THERMAL POWER PLANTS

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Abstract

In this study, the anatomical and morphological anomalies in the cross-section of Turkish pine needles (*Pinus brutia* Ten.) caused by air pollutants that was emitted from the Kemerköy (Gökova) Thermal Power Plant (KTPP) were investigated with fieldworks and microscopic techniques. At the end of the land researches, it was found out that air pollutants such as sulfur dioxide, nitrogen oxides and fly ash had caused serious injury, and caused 3 year-old-needles fell very early. On the microscopic observation on the cross-sections of the needles, it was determined that the diameter of the main and especially subordinate resin canal dilated too and the number of resin canals increased. It was also observed that the endodermis layer in transmission corymbs and the cells in transfusion texture had become thin, and the intra-cellular material had disappeared owing to air pollutants.

Key words: Thermal power plant, Turkish red pine, Needle, Cross-section anomaly.

Özet

Bu çalışmada Kemerköy (Gökova) Termik Santrali'nin (KTS) oluşturduğu hava kirleticilerin kızılçam iğne yaprak enkesitlerinde oluşturduğu anatomik ve morfolojik anomalilerin arazide ve mikroskobik çalışmalarla ortaya konulması hedeflenmiştir. Arazi çalışmaları sonucunda kükürt dioksit, azotoksit ve uçucu küllerin ibrelerde ciddi zararlar yarattığı ve 3 yaşındaki ibrelerin çok hızlı bir şekilde dökülmesine neden olduğu gözlemlenmiştir. Mikroskobik olarak yapılan gözlemlerde ise ana ve özellikle tali reçine kanallarında genişleme olduğu ve reçine kanalı sayısının arttığı tespit edilmiştir. İletim demetlerindeki endodermis tabakasında ve iletim demetlerinde incelmelerin meydana geldiği ve hücre içi dokuların kirlilikten ötürü zarar gördüğü gözlemlenmiştir.

Anahtar kelimeler: Termik santral, Kızılçam, İğne yaprak, En kesit anomalisi.

INTRODUCTION

Industrial development depends on commonly the combustion of fossil fuels for energy requirement and, by this aim, coal, lignite, fuel-oil, motor oil and natural gas are combusted. In Turkey, about 89.3 % of energy requirement is fossil fuels and it consist from 31.9 % natural gas, 14.1% lignite, 16.6% coal , 26.7 % petroleum, 4.1% hydrolic, 4.2% wood and litter and 2.4 % renewable and others Anonymous (2012).

Lignite used thermal power plant has low calorific degree and high fly ash, moisture and combustible sulfur. For this reason, by combustion of lignite, thermal power plants too much emitted sulfur dioxide and other pollutants into the atmosphere. The well recognized air pollutants, generally released from TPP, are nitrogen oxides, carbon monoxide, hydrogen fluoride, carbon dioxide and fly ash besides sulfur dioxide (Boubel et al. 1994, Nuhoğlu 2004). Particulate matter and about 99% of fly ash is trapped by cyclonic and electrostatic precipitators, but a considerable amount of fly ash escapes precipitation and is emitted into atmosphere. The elemental composition of fly ashes may vary widely, it usually contains plant nutrients besides toxic elements (Zerbe et al. 2001, Nuhoğlu and Bulbul 2003).

Gaseous air pollutants enter plant leaves through stomata during gas exchange of respiration, and then pass into the intercellular spaces of mesophyll tissue causing various anomalies of anatomical, morphological and physiological structure (Pogorzelski 2014, Gupta and Ghouse 1986, Nuhoğlu et al. 1996, Nuhoğlu 1993). The leaf epidermis, being an effective barrier for gaseous exchange and the outer-most protective layer in plants, exhibits modifications and abnormalities in form, structure and function with the changes in surrounding environment, and such modifications are likely to serve as indicators of air pollution (Pogorzelski 2014, Petkovsek et al., 2008, Gupta and Ghouse 1986, Nuhoğlu 2005).

The present research deals with the anatomical and morphological anomalies owing to air pollutants caused by the Kemerköy (Gökova) Thermal Power Plant on the cross-section of Turkish pine (*Pinus brutia* Ten.) needles. Turkish pine forests are utilized for wood requirement of Turkey at 23% extend and covers 3 096 064 ha spreading area in the Mediterranean region (Saatçioğlu and Odabaşı 1979). The aim of this research was to investigate the effect of air pollutants emitted from Kemerköy thermal power plant on the cross-sections of Turkish pine needles.

MATERIALS AND METHODS

The Kemerköy thermal power plant and the surrounding flora

The KTPP is in Gökova (Kerme) gulf (37º 02´ N, 27º 54´ E), 98 km far from Mugla in south extremity of the Aegean Region of Turkey (Fig. 1).

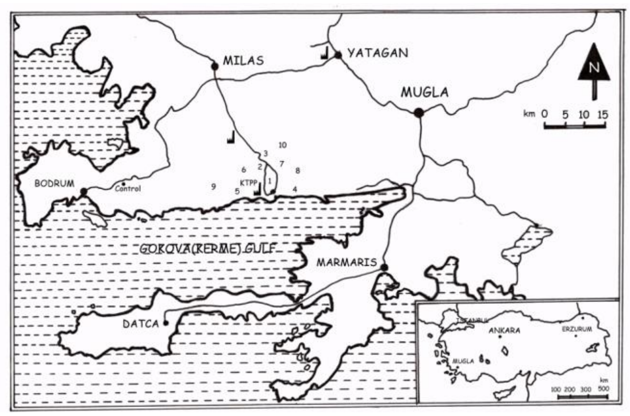

Fig.1. The position of the KTPP and the research points.

The KTPP was begun to operation in 1992. It is the third one of the triplet/thermal power plant complex in Mugla, is made up of three (and optional plus one) units having the power per unit of 210 MW, produces electricity by burning per unit 5000 t/d of lignite. The calorific degree of the lignite is 1550-2400 cal/g and it includes about 33% moisture, 32 % ash, 21.5 % carbon, 1.5 % hydrogen, 9.4% nitrogen+oxygen and 2.6% combustible sulfur (Anonymous 2000).

The KTPP releases 10^6 m^3/h chimney smoke per unit into the atmosphere. It consists of about 9000 mg/m^3 sulfur dioxide, 800 mg/m^3 nitrogen oxides, 600 mg/m^3 fly ash, 600 mg/m^3 carbon monoxide, 12 % carbon dioxide, 5 % oxygen and others (Anonymous 2002). The desulfurization plant of the KTPP has been construction.

The average age of natural Turkish pine forest is between 45-80 years old. Turkish pine is the dominant tree in the over storey of these areas. There are *Platanus orient*alis L., *Salix alba* L., *Juglans regia* L. and *Ulmus minor* L. in the valleys and the aside of streams. As an understorey characteristic scrubby (macchie) flora consists from more than 40 species. The part of these stands is classified as productive forest while the other part of them as protection. The soils are red-brown, brown and redzina. Soil depth is generally 30-300 cm. The forest is generally closed and rarely light as canopy closure (Saatçioğlu and Odabaşı 1979, Ceylan 1986). There are a number of villages and fields close to the forested areas.

METHODS

Ten different research points were chosen in order to determine the anatomic and morphologic anomalies on the Turkish pine needles (*Pinus brutia* Ten.) around the KTPP which is in Ören, Milas, Mugla (Fig.1). The south front of the KTPP is surrounded by completely the Gokova (Kerme) Gulf. There is a south-west wind around the KTPP. Since the air pollutants are carried towards the north-east direction because of south-west winds, the control-Turkish pine forest chose 40 km aerial line from the TPP in the direction of west.

The influence degree of 1, 2 (and 3)-year-old Turkish pine needles in their own natural surroundings was observed and determined through the field studies.

In the research points, terminal twigs included 3-years-old neddles at branches of the Turkish pines that are about 2 meter high from the ground were cut with gardening shears and transported to the laboratory in lidded-polyethylene bags. After the needles have been washed and wiped sections from the very middle of the needles were taken by means of razor blade under movable magnifying-class. By this way, the cross-sections of Turkish pine were obtained, and then they were prepared in microscope slides and cover-glass by the use of Canadian balsam. These preparations were examined under the Olympus PM-10 AD research microscope and their photographs were taken. Main and secondary resin canals, epidermis and hypodermis layers, parenchyma cells and transmission corymbs on the cross-sections of the needles of Turkish pine were examined and they were compared with the samples taken from the control point. The thickness of main and secondary resin canal diameters, epidermis and hypodermis layers were measured by micrometer mounted in the microscope. The diameters of main and subordinate resin canal were performed in the cross-sections of 100 needles (as the average of all main and subordinate resin canal diameters in every croos-section) measured taken from control and each of the research points.

T-test for dependent samples was performed on statistical analysis the comparison of the diameters of main and subordinate resin canals in the polluted and control points. At the same time, 'The Box and whiskers plot for all variables' were performed by descriptive statistics (as non-parametric statistic) for determined the differences of control and all of the research points as visually (by STATISTICA 6.0).

RESULTS

Plants are exposed to air pollutatnts emited from thermal power plants. Metabolic activities in plants depends on air pollutants according to the air pollutant concentrations and exposure time. This pollutants quickly reacts inside leaves, thus the metabolic activity is damaged and at the same time foliar damage occurs are became which lead to leaf injuries. Photosynthetic performance as indicated by atmospheric pollutants during combustion of lignite in TPP. Depending on the concentrations of air pollutants the needles were dried.

The results of this study indicate that the air pollutants had caused serious harm in Pinus brutia needles and that 2 and 3-year-old needles had been affected most by the pollutants. It was observed that 3-year-old needles in the 1st, the 2nd and the 7th research points had fallen one year ago owing to the effects of intensely air pollution.

The following differences were found out between the needle cross-sections in polluted and control points: The harmful effects of air pollutants emitted from KTPP can be seen in Figs. 3, 4 and 5 are compared with Fig. 2. The areas effected by the KTPP, dilation in resin canals and anomalies on resin canal positions, thinning in epidermis and hypodermis layers were observed in cross-sections of Turkish pine needles. In these sections, it was observed that especially subordinate resin canal diameters have dilated too much.

The dilation in resin canals can be clearly observed when Fig. 2 are compared with Figs. 2 and 5. Fig. 2 shows the cross-section of a one-year-old needle taken from the control point. The diameters of the main and subordinate resin canals in the cross-sections of those needles were calculated 37.05 ± 15.73 μm by finding the average score of 100 samples. Figs. 3 and 5 show two samples of the cross-section of one-year-old and two-year-old needles respectively taken from the areas under the harmful effects of SO_2, NO_x and fly ash released into the atmosphere from the chimney of KTPP. What is observed in this cross-section is that subordinate resin canals' diameters have been as large as those of main canals and that resin canals' diameters have dilated too much. In the measurements performed on 100 of one-year-old needle samples in the 1st research point, the diameters of resin canals were found to be 55.95 ± 15.87 μm. These increases found especially on two-year-old needles belong to the polluted points such as the 1st, the 2nd and the 7th research points (see Figure 5). The less the pollution is, the more normal the diameters of resin canals are. This occurrence may be by two reasons. Firstly, the Turkish pine injuries air pollutants of the TPP, and pathogens or insects attaches towards this sensitive (injured) plants (Krupa and Manning 1988). Thus, the Turkish pine exudes most resin to protect of its vitality and it increases the amount of resin released and thus cause dilation in resin canals. Secondly, during the photosynthesis, sulfur dioxide and hydrogen fluoride turn into sulfuric and hydrofluoric acid as a result of various reactions within the needle texture after they have passively been taken into the needle with polluted air. Because sulfuric acid is a resin-exude agent, by these ways it is augmented the amount of resin-released and excessive released resin has pressed in the internal resin canal surfaces, thus cause dilation in the resin canals. The more the resin exudation is, the more the resin canal volume and diameter are. Figs. 3 and 4 show that a cross-section of Turkish pine needle injured by air pollutants emitted from the chimney of KTPP. In addition, certain metals found in the fly ash such as Cu^{+2}, Mn^{+2}, Fe^{+2}, Co^{+2}, Ni^{+2} and the salts of these metals become catalysts and thus sulfur dioxide, nitrogen oxides, carbon dioxide and hydrogen fluoride turn into acid rain (Seinfeld 1975, Irwin and Williams 1988). The acid rain touches the needles of the plant and causes necroses on them. Resin, which dilates the canals by applying pressure on them, goes out of these necroses. Therefore, cracks appear in resin canal. In the land research, it was observed that there had appeared a leak of resin from these cracks, and that this leak had covered the whole surface of the needles as drops especially dusty needles.

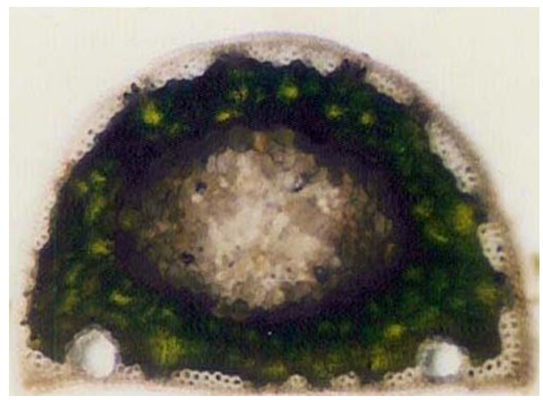

Fig. 2. Cross-section of one-year-old needle taken from the control point (x 80).

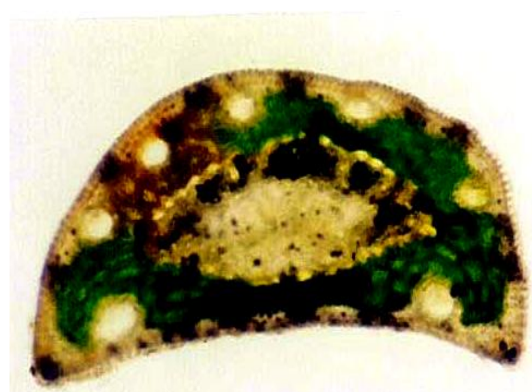

Fig. 3. Cross-section of one-year-old needle taken from the 1st research point (x 80).

Fig. 4. Cross-section of one-year-old needle taken from the 1st research point (x150).

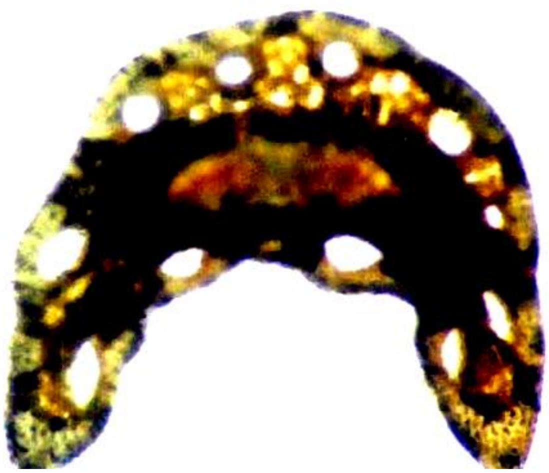

Fig. 5. Cross-section of two-year-old needle taken from the 1st research point (x 80).

Normally, there are two main and five subordinate resin canals in the cross-section of a needle; however, there are 2 main and 6-9 subordinate resin canals in the cross-sections of the needle in polluted points (see Figs. 3 and 5). That is, air pollutants inrease the number of resin canals and main and especially subordinate resin canal diameters in time. It was performed statistical analysis between the resin canal diameters of one-year-old needles taken from control and all of the research points in order to prove this expression.

Table 1 shows the main and subordinate resin canal diameters measured on 100 samples in control and all of the research points. The difference of resin canal diameter in all of the research points were performed by the t-test (The STATISTICA 6.0).

Table 1. The resin canal diameters measured on 100 samples in all of the research points.

Research points	**Mean Resin canal diameter (µm)**	**Std. dev.**	**Std.dev.Diff.**	**T- values**	**P-values**
1	55.950	15.87	22.803	-8.288	0.0000*
2	50.550	15.43	20.232	-6.672	0.0000*
3	45.450	13.69	20.509	-4.095	0.0000*
4	37.400	12.60	20.964	-0.166	0.8677
5	45.350	17.65	21.709	-3.823	0.0002*
6	45.100	15.47	22.404	-3.593	0.0005*
7	52.600	17.06	24.098	-6.452	0.0000*
8	48.600	14.87	23.481	-4.918	0.0000*
9	39.300	14.37	18.794	-1.197	0.2340
10	47.950	13.83	21.653	-5.053	0.0000*
Control	37.050	15.73	0.000	0.000	1.0000

*Marked differences are significant at $p < 0,05$.

When evaluated Table 1, it is seen that there are significant differences at $p < 0,05$ between the 1st, the 2nd, the 3rd, the 5th, the 6th, the 7th, the 8th and the 10th research points and there isn't significant difference with 4th and 9th research point with control point. By means of t-test, the dilation of resin canal diameter owing to air pollutants emitted from the KTPP has been confirmed by statistical analysis.

At the same time, 'The Box and whisker plot' were performed by descriptive statistics (as non-parametric statistic) in order to fit the difference of resin canal diameter in all of the research points as visual. 'The Box and whisker plot' is indicated the difference of resin canal diameter in all of the research points as perfectly shown in Fig. 6.

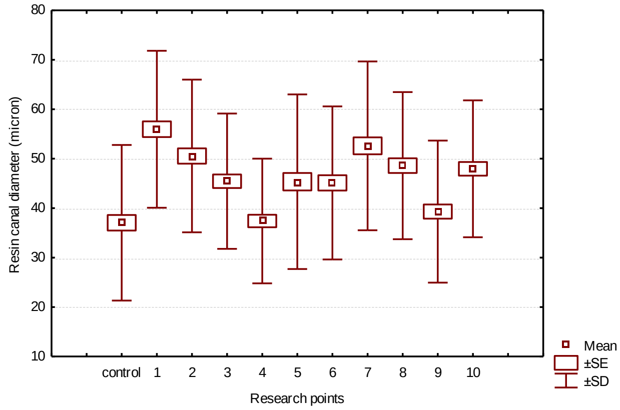

Fig.6. The differences of resin canal diameter in all of the research points as 'The Box and whisker plot for all variables'.

When evaluated together Table 1 and Fig. 6, it is seen that the resin canal diameters in the the 1st, the 2nd, the 7th and the 10th research points are the most effected by air pollutants. The reason of this occurrence attribute to the air pollutants are carried towards the north-east direction because of south-west winds. The resin canal diameters in the other research points such as the 3rd, the 5th, the 6th and the 8th are more effected.

Air pollutants do not only injury the anatomical and morphological structure of the needle, they also injury transmission corymbs. Fig. 4 show the corymbs in the cross-sections of the needles taken from polluted points. From them, it is clearly observed in the needle that the endodermis layers and transfusion tissue cells have lost their characteristics and have been deformed, gaps have occurred within the cells after the intra-cellular material has disappeared and that the cells have lost their vitality. In addition, the cytoplasmic material in the parenchyma cells found in the needles in the polluted points has lost its natural density and structure.

DISCUSSION

There are resembling research in this issue such as the effect of sulfur dioxide and other pollutants on the anatomic and morphologic changes of needles and stem anatomy of Scots pine (Smith and Davis 1978, Suchara et al. 2014, Mortensen et al. 1989), other conifers (Burkhardt and Pariyar 2014, Nuhoğlu 1993, Tjoelker and Luxmoore 1991, Meng et al. 1995, Soda et al. 2000, Okano et al 1985), and the other plants Nuhoğlu 2005, Anonymous 2000, Anonymous 2002, Günthardt-Goerg et al. 1993), but there are no research the anatomic and morphologic changes of the cross section of Turkish pine's needles caused by air pollutants in Turkey and the other countries. For this reason, it is estimated that the findings about the anomalies of cross-section of Turkish pine's needles owing to air pollutants emitted from thermal power plants are investigated firstly.

These research series have been carried out since 1991, but they submit to international audience via this paper. First research results had obtained at 1993 before GTPP was to operation. That research performed 30 research point around the thermal power plant complexes in Mugla. The measurements performed on 35 samples of each research point, and the diameters of resin canals were found to be 22.80±7.40 and 79.20±18.30 μm in control and polluted research points respectively (as x±SE). It was determined out that the increasing of resin canal diameters correlated to air pollution degree[8]. Secondly, the other research performed on 15 research point around the Yatagan thermal power plant. The measurements performed on 35 samples of each research point, and the diameters of resin canals were found to be 20.70±7.70 and 77.20±17.70 μm in control and polluted research points respectively (as x±SE) [10]. At the same time, these researches proved that the amount of chlorophyll in the needles in polluted points, especially that of chlorophyll-a had decreased.

CONCLUSION

This study shows that the air pollutants emitted by the chimney of the KTPP caused thinning in epidermis and hypodermis layers, anomalies on resin canal positions and dilation in canals. It was determined that main and especially subordinate resin canal diameters had dilated too much, the endodermis layer in transmission corymbs and the cells in transfusion tissue, and the intra-cellular material had disappeared and that gaps had come out in the inner side of the cells. The dilation of resin canal diameter owing to air pollutants emitted from the KTPP has been confirmed by statistical analysis.

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