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ARTÍCULO

The influence of road traffic and industrial plant-induced air pollution on the physical, mechanical, chemical, and morphological properties of the black pine wood

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Abstract:
Road traffic pollution and industrial plant-induced pollution affect negatively the development of forest trees. How forest trees are affected by their growing environment is important for sustainable environment. The study aimed to investigate the physical, mechanical, chemical, and morphological properties of the *Pinus nigra* (black pine) tree which grows under different conditions. Tree samples were chosen from three different lands where were inside the forest (O), near the roadside (Y), and near the factory (F). It was studied whether there were any significant differences among the "O", "Y" and "F" in terms of their wood properties such as physical, mechanical, chemical, and morphological. As a result, the "O" samples demonstrated more regular annual ring structure. On the other hand, it was observed that the "Y" samples had longer and wider tracheid cells. In addition, "Y" samples had better mechanical strength than "O" and "F". Environmental pollution caused the presence of some different elements (chlorine and iron) in "Y" and "F". As a result, it was determined that the trees growing near the roadside or near industrial plants have significant differences from forest trees which are far away from pollutions. It is possible to say that *Pinus nigra* (black pine) is resistant to environmental stress. For this reason, it can be recommended to use it as a barrier to reduce air pollution on the roadsides.

Keywords: Black pine wood, industrial plant-induced air pollution, road traffic pollution, sustainable environment, wood characterization.

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Introduction

The human population has increased rapidly; because of this, the pressure on the ecological balance has increased. This pressure especially affects forest resources. Human beings and rapid development in technology harm forests directly or indirectly. Trees that grow on roadsides or near industrial areas are greatly affected by these conditions.

Apart from these conditions, wood is also affected by many other parameters. The physical properties of the wooden material depend on the structure of the wood (density, chemical structure, cutting direction, fiber-load angle, earlywood/latewood, heartwood/sapwood), environmental effects (relative humidity, temperature, surrounding media, aggressive media), previous processes (drying method, impregnation). It varies depending on the test method (sample geometry, test type, test speed, load duration, static/dynamic testing).

In studies on the density distribution of trees, it has been reported that Douglas fir has a density between 420-490 kg/m^3 (Maeglin *et al.* 1972) and radiata pine has a density between 390-470 kg/m^3 (Delmastro *et al.* 1982), depending on geographical conditions (Walker 2006, Niemz *et al.* 2023)

Over the past decade, the effects of rapid climate changes thought to be caused by human activities on tree species have become the subject of increased research. Trees respond to human-based environmental stress such as decreased growth, increased heterogeneity in annual ring growth, and decreased sensitivity to short-term environmental impulses (Anderegg *et al.* 2015, Sensuła *et al.* 2021).

Treesare affected by the conditions in their environment (climate, soil, altitude). Forest trees have changed under the influence of environmental factors throughout their ecological history (Hamrick 2004, Oberhuber *et al.* 2015, Vospernik *et al.* 2018, Bosela *et al.* 2019, Leštianska *et al.* 2023,). Wood is produced by the vascular cambium, which is one of the meristematic cells of the tree. As cambium tissue divides and grows, it is affected by its immediate environment, genetic structure, climate, and the soil in which it is located.

Environmental conditions (climate and nutritional factors) change over (Niemz *et al.* 2023). As a result, these changes cause changes in the annual ring and chemical structure of the wood (Downes *et al.* 2008, R. You *et al.* 2021, Marais *et al.* 2022,). Leonelli *et al.*(2016) analyzed approximately five trees per km in 360 km of forestland in Upper Valtellina in the Italian Alps and analyzed 1814 trees to determine environmental factors limiting tree line height. They reported that 82 % of trees were affected by geomorphological constraints, while only 3 % of trees were affected by human influence.

The biochemical, morphological, and physiological characteristics of trees may be different in terms of their largeness and growing areas (Grote *et al.* 2016). For this reason, samples taken from the same tree species but grown in different areas may show different characteristics. Trees are in balance with their environment because they have naturally been adapted to forest ecosystem for centuries (Bussotti and Pollastrini 2021).

However, trees may be stressed due to human-based environmental influences. These stress factors can be listed such as soil pollution and air pollution. Trees located near the factory may be exposed to various chemicals, depending on the type of factory and whether it has filters or not. Thus, chemical stress factors occur distinctly from vehicle traffic stress.

Trees that grow by the roadside help to reduce particulate pollution caused by traffic (Ozdemir 2019), but thegrowth efficiency of trees is also reduced while helping to reduce pollution. It was reported that some trees (banyan (*Ficus benghalensis* L.), *Eucalyptus* sp., guaiac (*Guaiacum officinale* L.), button wood (*Conocarpus erectus* L.) were affected by the exhaust gases of vehicles. Thus, their leaf surface area, amount of chlorophyll in the leaves and the dry wood weights decreased.

However, some species neem (*Azadirachta indica* A. Juss.) have shown resistance to exhaust emissions (Bhatti and Iqbai 1988, Iqbal *et al.* 2015). Also, trees that grow close to industrial plants are adversely affected by environmental factors such as gases, factory chimneys, noise and dust. These effects may affect the fiber properties in the wood structure. The fiber properties of wood largely affect the suitability of the pulp and paper industry processing, as well as in sawmills (Paavilainen 1993). Also, fiber morphology and cell wall structure directly affect fiber flexibility, plasticity and processing resistance, and therefore, the strength and other physical and optical properties of the final products are affected (Seth and Page 1988).

In addition, wood density is also an important wood property related to the yield and quality of pulp and sawn products (Mäkinen and Hynynen 2012). Trees growing on the roadside are most exposed to urban stress factors (Sæbø *et al.* 2005). Joshi and Swami (2007) found in their study that roadside trees give physiological responses to vehicle pollution stress. It is thought that the difference between the ages of the samples with similar diameter and height values is related to the conditions of the habitat.

In their research, Dmuchowski *et al.* (2013) observed that the decline of trees was due to the gradual weakening of their vitality. They reported that trees growing near roads are generally more affected by human-induced environmental impacts. Disadvantages of the urban environment, such as salt sprinkled on the roads to prevent the roads from icing, constant changes in the city climate (high temperature, decreasing air humidity), traffic (high levels of smoke and dust), negatively affect the development of trees (Dmuchowski *et al.* 2013, Szypowski 2000).

Forest provides several benefits to society in ecological, economic, and social purposes. Thus, they must protect themselves for the next generation. This is also important for the planning of forests.

In this paper human-based environmental impacts were studied. The study aims to investigate the chemical, physical, mechanical, and morphological properties of black pine (*Pinus nigra* J.F. Arnold) tree which grow in the forest, near roadside, and near the factory. The selection of suitable tree species is very important in terms of sustainable forestry. In this context, it should be known how human-based environmental conditions such as roads and factories affect the growth of the trees.

At this point, using resistant species will be more ecologically effective. In the study, black pine (*Pinus nigra* J.F. Arnold) trees were selected since black pine (*Pinus nigra* J.F. Arnold) has the largest growing area in Türkiye after red pine (*Pinus brutia* Ten.) (OGM 2021).

Black pine (*Pinus nigra* J.F. Arnold) trees cover the Bolu district's land by 59 % in Türkiye. Black pine (*Pinus nigra* J.F. Arnold) is one of most prevalent tree species in Bolu district (OGM 2021). Black pine (*Pinus nigra* J.F. Arnold) can grow under many different conditions. Therefore, it is widely used in the forest industry (Uner *et al.* 2009). In this study, black pine (*Pinus nigra* J.F. Arnold) samples were chosen from three different locations. The first tree was cut into the forest, the second one was cut near the road and the third one was cut in front of the factory. These trees were characterized from mechanical, physical, morphological, and chemical aspects according to relevant standards and then differences and similarities were statically revealed.

Materials and methods

Study field

In this study, black pine (*Pinus nigra* J.F. Arnold) trees were cut from three different regions (Figure 1). First was in the forest (O), second was near the roadside (Y) and third was in front of the factory (F) respectively. Trees were within the borders of Bolu district in Türkiye. “O” samples was 55 years old, 16,5 m height, 30 cm diameter, and 750 m inland from the road (D160). The second tree that is “Y” sample was near road side which responsibility belongs to the Sırçalı Forest Management/Mudurnu/Bolu/Türkiye. “Y” was 48 years old, 17 m height, and 30 cm diameter. Third tree that is “F” sample was in front of the factory which was from the No. 21 region which is under responsibility of Mudurnu Forest Management/Bolu/ Türkiye. This region was 165 m far from the main road. The tree was 22 years old, 16,5 m height, and 24 cm diameter. All samples (O, Y, F) were taken from northern front.

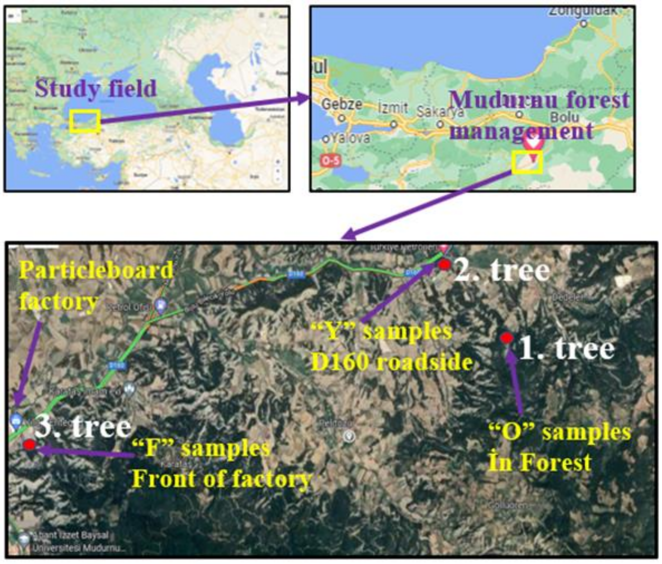

Figure 1: Study field and O, Y, F samples taken points (Google maps 2022).

Methods

The trees were cut on 09.12.2021 with the permission of Mudurnu Forestry Management. In the study, the “O” sample was coded as O(1), O(2), O(3),the “Y” sample was coded as Y(1), Y(2), Y(3), and the “F” sample was coded as F(1), F(2), F(3)according to height from the soil level. O(1), Y(1), F(1)represent 1,30 m –1,80m height of the tree, O(2), Y(2), F(2)represent 1,80 m –2,30m height of the tree and O(3), Y(3), F(3)represent 2,30 m –2,80m height of the tree from the soil level. Samples were coded as “O”, “Y” and “F” for the chemical and morphological analysis. Elemental compositions and textural differences of the trees were revealed by performing SEM-EDX analyses. The diameter and height of the trees were arranged as same as possible (30 cm diameter and 16m height).

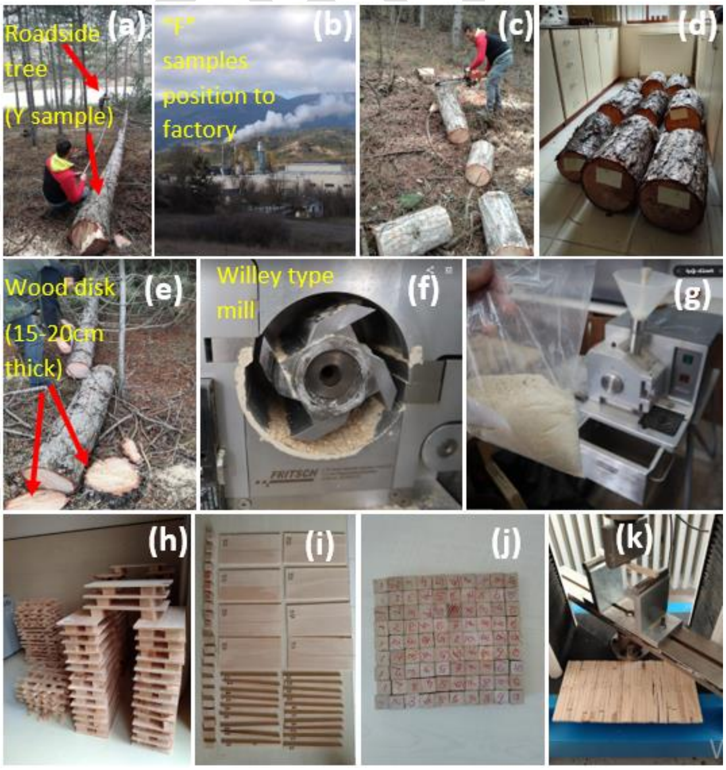

Figure 2:(a) roadside tree for Y samples, (b) particle board factory, F samples, (c) tree cutting by 50 cm, (d) logs were air dried, (e) wood disc, (f) Willey mill, (g) milled chips, (h) samples

were air dried, (i) bending and sheer test samples, (j) pressure test samples, (k) mechanical analysis.

Chemical analysis

Test samples were cut from tree body (Figure 2e) according to TAPPI T-264 (1997) standard which was used in the preparation of samples for chemical analysis. Barks of the samples were peeled and chopped manually. Then, chipped wood was ground in a Willey type mill (Figure 2f) and samples were sieved through a 60-mesh (Figure 2g) for chemical analysis. Chemical tests and related standards are given in Table 1. Analyses were performed in 3 repetitions and calculated as a percentage of the dry wood weight.

Table 1: Chemical analysis standards.

Chemical analyses	Standards
Holocellulose determination	Chlorite method[1]
α-cellulose determination	[2]
Lignin determination	[3]
Alcohol solubility	[4]
Hot water solubility	[5]
Cold water solubility	[6]
1 % NaOH solubility	[7]

[1] Wise and Karl (1962); [2]Rowell (2005);[3] TAPPI T-222 (2006),[4]TAPPI T-204 (2007), [5]TAPPI T-207 (1999), [6]TAPPI T-207 (1999), [7] TAPPI T-212 (2018).

Physical and mechanical analysis

Test sample cutting and preparation processes were made according to TS EN 326-1 (1999) standard. Physical properties which were moisture (MC; n:40), density (DN; n:40), water absorption (WA; n:40), and thickness swelling (TS; n:40) analyses were performed according to TS EN 321(2005), TS EN 323 (1999), TS EN 321(2005) and TS ISO 13061-15 (2021) standards, respectively. Mechanical properties which were modulus of rapture (MOR; n:150), lap sheer strength (LSS; n:150), and pressure (PS; n:150) analyses were performed using TS EN 310 (1999), TS ISO 13061-8 (2022) and TS ISO 13061-5 (2021) standards, respectively.

Morphological properties

Maceration process was applied to wood samples to determine the morphological properties of wood fiber. For this purpose, chipped wood samples were treated with sodium chloride and acetic acid (Wise and John 1952). At the end of the process, individual fiber samples were placed between the lamel and lamella. The length and width of tracheid, lumen width and double wall thickness of the tracheid were investigated using the Olympus CX21 binocular light microscope. For tracheid lengths, x10 objective (1 division = 10 µm) and x40 objective (1 division = 2,5 µm) were used for other measurements. 100 random measurements for tracheid length and 50 measurements for other features were averaged.

Statistical analysis

SPSS 23 package program was used in the statistical evaluation of the data. One-way analysis of Variance (Anova) was used to determine whether a significant difference between the analysis results of the samples taken from different locations. Duncan, one of the post hoc tests, was used to determine the different sample groups.

Results and discussion

Chemical analysis results

In chemical analysis, holocellulose, α-cellulose and lignin main components of “O”, “Y” and “F” samples, as well as solubility in hot water, cold water, 1 % NaOH and alcohol, were determined (Table 2).

Table 2: Holocellulose, α-cellulose and lignin determination and some solubility of samples.

Samples	Holocellulose (%)	α-Cellulose (%)	Lignin (%)	Hot water solubility (%)	Cold water solubility (%)	1 % NaOH solubility (%)	Alcohol solubility (%)
	Sig. = 0,065	Sig. = 0,074	Sig. = 0,086	Sig. = 0,014	Sig. = 0,000	Sig. = 0,771	Sig. = 0,023
O	72,7 B* (± 0,1)	50,8 B (±1,1)	27,5 B (±0,5)	4,21 A (±0,03)	2,05 A (±0,05)	12,6 A (±0,8)	3,41 A (±0,3)
Y	72,5 AB (± 0,2)	50,1 AB (± 2,1)	27,1 AB (±0,5)	4,52 B (± 0,14)	2,98 B (± 0,01)	12,9 A (± 0,3)	3,89 B (± 0,03)
F	71,9 A (± 0,5)	47,5 A (± 0,6)	26,4 A (± 0,5)	4,13 A (± 0,13)	1,95 A (± 0,08)	12,4 A (± 1)	3,37 A (± 0,1)

* Duncan analysis groups. ($p \leq 0,05$ of significant level).

Table 2 demonstrates that there was no significant difference in the major contents of holocellulose, α-cellulose, and lignin of the “O”, “Y”, and “F” samples ($p \geq 0,05$). The average holocellulose content is 72,7 %; 72,5 % and 71,9 % for “O”, “Y”, and “F”, respectively. The α-cellulose content is 50,8 %; 50,1 %; 47,5 % and the lignin content is 27,5 %; 27,1 % and 26,4 %. The results are like some studies (As *et al.* 2001, Guler *et al.* 2007, Kiliç *et al.* 2010). However, it is feasible to see different results for the same species (Akyürek 2019).

Wood structure is affected by genetic, environmental, and anthropogenic factors that are effective during the formation of cells and tissues (Wodzicki 2001). Negative anthropogenic factors such as air pollution also cause biochemical reactions in trees (Judzentiene *et al.* 2007). The fact that no difference was detected in the main components of the study samples grown on the roadside and near the factory and exposed to air pollution in our study is an indication that air pollution does not affect these characteristics.

Krutul *et al.* (2014) reported that environmental pollution did not affect the cellulose and lignin content in oak samples. Also, Krutul *et al.* (2006) reported that lignin content in the wood taken from 1km and 21km from the power plant was higher than onein wood taken from the forest. In another study, the characteristics of trees growing on the roadside and in the forest were investigated, and reported that the cellulose and lignin contents were in the area with the highest environmental stress. In addition, it has been reported that the solute content in NaOH and EtOH is higher in urban agglomeration (Kusiak *et al.* 2020).

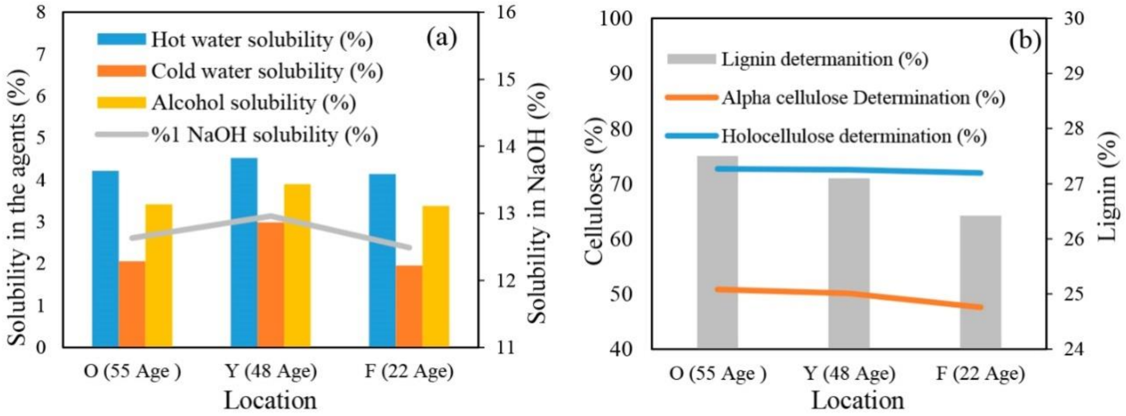

Figure 3: (a) Solubility of samples, (b) holocellulose, lignin, and alpha-cellulose determination of samples.

The differences between the solubility values of the "O", "Y", and "F" samples are shown in Figure 3. According to the statistical evaluation, it was observed that other solubility, except 1 % NaOH solubility, created significant differences ($p \leq 0,05$). Solubility values are determinant of the amount of extractive substance in the wood. Hot and cold-water solubility, inorganic substances, sugars, tannins, polysaccharides, salts, dyestuffs, organic acids, phenolic compounds, gums, alcohol solubility, and flavonoid and stilbenes in wood are determined.

With 1 % NaOH solubility, low molecule-weighted carbohydrates, fragmented cellulose, and polyoses in wood are determined (Fengel and Wegener 1984). It was determined that the amount of extractive substance of "Y" samples was higher than that of "O" and "F" samples. Extractive substances have an important effect on the physical and mechanical properties of wood, as well as on properties such as permeability, durability, and adaptation to external weather conditions (Sivrikaya *et al.* 2011). Based on this, it can be said that the increase in the amount of extractive substance in the Y sample may be caused by road pollution.

In a similar study, Krutul *et al.* (2014) found that the amount of extractive substance in oak trees grown in a polluted environment increased by 2 %. Contrary to our study, Krutul *et al.* (2011) stated that environmental pollution also significantly affects 1 % NaOH solubility in birch. A similar result was also reported by Waliszewska *et al.* (2019) Depending on the results of the studies, extractive substances show a protective feature against environmental pollution as well as natural resistance.

Physical analysis results

Table 3 shows that there is no significant difference between the moisture (MC) values (8 % - 9 %) of the samples, but there are significant differences in density, water absorption (WA), and thickness swelling (TS) values both within and between groups. When Figure 4a is examined, it is seen that the lowest density sample (460 kg/m^3) is "O". The densities of “F” and “Y” samples are 480 kg/m^3 and 490 kg/m^3 respectively.

As the wood density decreases, more water molecules can bind between the cellulose molecules. This phenomenon causes to increase in the moisture content (MC) of the wood. There is an interaction among density and water uptake (Niemz *et al.* 2023). The results obtained confirm that the MC increases as the density decreases. Bal and Bektaş (2018) obtained similar results in their study. In terms of WA and TS values, there are significant differences between the samples (except 24 h WA). It is seen that WA and TS values of “O” are higher than those of “Y” and “F” (Figure 4b). It can be said that the reason for this is the density of the “O” sample is lower than the others (Figure 4a).

Table 3: Some physical properties of wood samples.

Samples	DN (Dry) (kg/m^3) Sig.= 0,001	MC (%) Sig.= 0,001	2-hour TS (%) Sig.= 0,001	2-hour WA (%) Sig.= 0,001	24-hour TS (%) Sig.= 0,014	24-hour WA (%) Sig.= 0,006
O(1)	450 A (± 30)	8,6 A (± 1,2)	6,01 BC (± 0,01)	61 D (± 0,02)	6,4 AB (± 0,01)	72 C (± 0,03)
O(2)	450 A (± 20)	8,8 A (± 1,4)	6,6 CD (± 0,01)	60 D (± 0,18)	6,8 B (± 0,01)	70 BC (± 0,12)
O(3)	470 A (± 40)	9,3 A (± 1,1)	6,5 7 (± 0,01)	57 CD (± 0,09)	6,9 B (± 0,01)	71 BC (± 0,11)
Y(1)	480 AB (± 20)	7,9 A (± 1,2)	4,9 B (± 0,01)	48 AB (± 0,08)	5,8 A (± 0,01)	65 AB (± 0,05)
Y(2)	500 BC (± 30)	7,6 A (± 1,5)	5,3 B (± 0,01)	46 AB (± 0,05)	6,5 AB (± 0,01)	63 AB (± 0,06)
Y(3)	510 C (± 20)	7,7 A (± 1,3)	6,4 CD (± 0,01)	50 BC (± 0,06)	6,9 B (± 0,01)	63 AB (± 0,04)
F(1)	46 7 (± 30)	8,4 A (± 1,2)	3,9 A (± 0,01)	48 AB (± 0,13)	5,7 A (± 0,01)	69 BC (± 0,08)
F(2)	470 A (± 30)	8,4 A (± 1,4)	3,8 A (± 0,01)	44 AB (± 0,01)	5,7 A (± 0,01)	68 ABC (± 0,09)
F(3)	500 BC (± 40)	8,1 A (± 1,2)	4 A (± 0,01)	39 A (± 0,06)	6,2 AB (± 0,01)	60 A (± 0,04)

* Duncan analysis groups. ($p \leq 0.05$ of significant level).

The correlation between the mechanical strength value of a tree and its density can be expected to be higher in extracted wood compared to unextracted wood (Oliva *et al.* 2006). Similar results were obtained in the study.

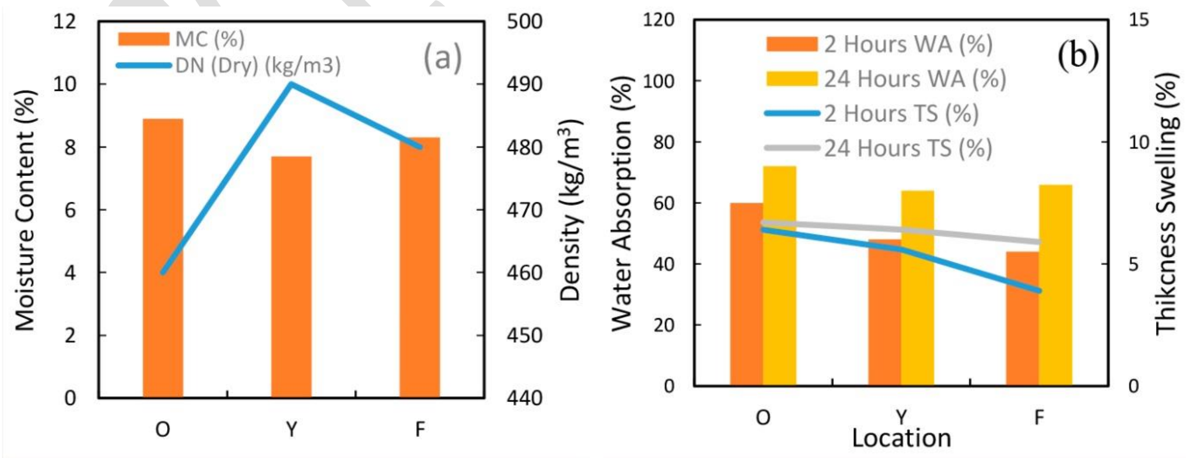

Figure 4: (a) Moisture content (MC) and Density, (b) Thickness swelling (TS) and water absorption (WA) of the wood samples.

According to the physical results, it was determined that the wood sample taken from the forest showed more swelling to its thickness than the samples taken from the roadside and the factory. The water absorption is a negative feature of wood material. In this case, it can be said that the black pine (*Pinus nigra* J.F. Arnold) species is less affected by environmental stress that is it absorbs less water than forest trees.

The growth of black pine (*Pinus nigra* J.F. Arnold) on the roadside caused the tree to grow slowly, increase its density and, decrease the swelling rate accordingly. Considering that moisture exchange is an undesirable feature in wood material, but it is seen that growing on the roadside does not adversely affect the wood in terms of WA and TS. In fact, there was a positive effect according to the results.

The amount of swelling of the wood depends on the density of the wood and the diffusion of water into the wood. It determines the speed at which water moves from the surface into the interior of the wood. The porous structure and chemical components of wood affect the amount of swelling (Khazaei 2008). In their workbook, Niemz (2010) report that the maximum moisture content of kiln-dry wood decreases from 500 % to 50 % as the density increases from 200 kg/m^3 to 1400 kg/m^3.

Mechanical analysis results

According to the statistical results, it was determined that there were significant differences ($p \leq 0,05$) between the MOR, MOE, LSS, and PS values of samples. Analysis results of mechanical properties are given in Table 4. MOR, MOE (Figure 5a) and PS (Figure 5b) values were highest (x_{MOR}: 73,7 MPa) in “Y” samples and lowest (x_{MOR}: 48,8 MPa) in “F” samples determined. In contrast to the MOR, MOE and PS analyses, the “Y” sample received the lowest value in the LSS analysis (x_{LSS}: 5,1 MPa) (Figure 5b).

This may be due to the different adhesion strength of Polyvinyl acetate (PVA) glue used as an adhesive in LSS analysis, depending on wood densities. However, in some studies, it has been reported that wood with higher density has better adhesion resistance or density does not have a significant effect on adhesion (Atar 2007, Perçin *et al.* 2009).

Table 4: Some mechanical properties and statistical results of wood samples.

Samples	Flexural MOR (MPa) Sig. = 0,001	Flexural MOE (MPa) Sig. = 0,001	Lap shear strength (MPa) Sig. = 0,001	Compressive strength (MPa) Sig. = 0,001	Deformation (%) Sig. = 0,001
$O_{(1)}$	76,9 F* (± 6,7)	4174 E (± 436)	5,9 BC (± 2,23)	48,7 EF (± 1,43)	1,62 AB (± 1,13)
$O_{(2)}$	64,7 D (± 6,3)	3629 CD (± 390)	5,9 BC (± 1,43)	44,8 D (± 1,43)	1,32 A (± 0,26)
$O_{(3)}$	67,95 D (± 7,2)	3747 D (± 434)	6,4 C (± 1,45)	43,6 D (± 1,43)	1,31 A (± 0,43)
$Y_{(1)}$	73,1 E (± 8,5)	3476 CD (± 696)	5,2 AB (± 0,83)	49,38 F (± 1,43)	1,93 C (± 0,95)
$Y_{(2)}$	82 G (± 9,8)	4270 E (± 933)	5,4 AB (± 2,39)	46,9 E (± 1,43)	1,43 AB (± 0,65)
$Y_{(3)}$	66,2 D (± 12,7)	3498 CD (± 605)	4,6 A (± 1,82)	48,2 EF (± 1,43)	1,62 AB (± 0,71)
$F_{(1)}$	55,6 C (± 9,1)	3363 C (± 736)	6,4 C (± 2,37)	31,2 A (± 1,43)	1,63 B (± 0,58)
$F_{(2)}$	41,9 A (± 10,7)	2405 A (± 960)	4,7 A (± 1,54)	34,5 B (± 1,43)	1,49 AB (± 0,41)
$F_{(3)}$	49,1 B (± 5,2)	2810 B (± 439)	5,6 ABC (± 1,63)	37,4 C (± 1,43)	1,52 AB (± 0,58)

*Duncan analysis groups. ($p \leq 0,05$ of significant level).

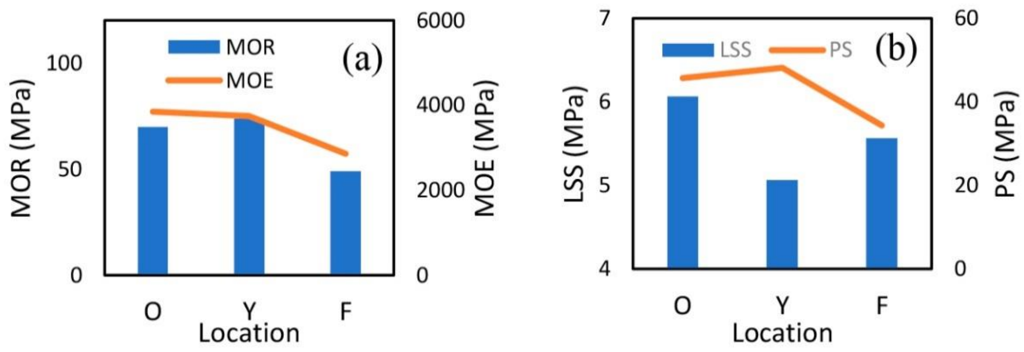

Figure5:(a) Modulus of rupture (MOR) and Modulus of elasticity (MOE), (b) Lap shear strength (LSS) and Pressure strength (PS)of the wood samples.

In other studies, it is reported that the quality of wood mainly depends on the density. (Kollmann *et al.* 1975, Pernestal *et al.* 1995, Oliva *et al.* 2006). It can be said that the higher density of the "Y" sample is the reason for the better mechanical properties (except LSS). However the same is not true for the F sample. Because although its density is higher than the "O" sample, its mechanical properties are lower.

The increase in density in F samples may have been caused by the excess of extractive substances other than wood tissues. Because although the "F" sample is younger than the "O" sample, it has grown faster, and its density is expected to be lower as a result. When the SEM images of the "F" samples are examined (Figure 8), it is seen that the wood tissues are more deteriorated than the "O" samples. It can be said that this causes the "F" samples to have lower mechanical strength than the "O" samples. More studies are needed on the effect of wood density and species on LSS resistance.

Table 5: Specific mechanical properties of wood samples.

Samples	MOR (MPa)	MOE (MPa)	Lap Sheer Strength (MPa)	Pressure strength (MPa)
O (1)	169,5	9198	13,0	107,3
O (2)	143,3	8040	13,1	99,3
O (3)	145,7	8034	13,7	93,5
Y (1)	153,8	7312	10,9	103,9
Y (2)	165,1	8595	10,9	94,4
Y (3)	129,3	6835	9,0	94,2
F (1)	121,0	7320	13,9	67,9
F (2)	90,0	5165	10,1	74,1
F (3)	97,2	5565	11,1	74,1

Specific mechanical properties were given in Table 5 which were calculated by dividing the mechanical properties by density for each sample due to the density difference. It was seen that specific mechanical properties are closely the same as Table 4. Thus, it can be said that density and mechanical properties were in direct proportion.

Morphologic analysis results

When the tracheid length and width of the wood samples were examined, it was determined that the tracheid lengths (3895 µm) and widths (48,15 µm) of the “Y” samples were higher than those of the “O” and “F” samples (Table 6). Similar results were obtained in lumen width and double wall thickness measurements. It was determined that the tracheids of “Y” samples were larger (7 % - 58 %) than the O and F samples. Similar results to O samples have been reported in different studies on black pine (*Pinus nigra* J.F. Arnold) tracheid measurements. (Doğu and Yılgör 2001, İstek *et al.* 2008, Köksal and Pekgözlü 2016). Reaction in wood formation shortens the tracheid length in the wood (Köksal and Pekgözlü 2016). In addition, it has been reported that the length of the tracheids in wood up to the age of 75 is longer than the previous year and shorter in the following years (İstek *et al.* 2008). But here, the reaction in wood formation was not detected in O, Y, and wood samples.

Table 6: Morphological properties and statistical* results of wood samples.

Samples	Tracheid length (µm) Sig. = 0,001	Tracheid width (µm) Sig. = 0,001	Lumen width (µm) Sig. = 0,211	Cell wall thickness (µm) Sig.= 0,004
O	3639 B* (± 448)	46,05 B (± 8)	30,8 A (± 12)	15,1 AB (± 7)
Y	3895 C (± 1098)	48,15 B (± 9)	30,9 A (± 13)	17,2 B (± 8)
F	2515 A (± 455)	39,6 A (± 9)	27,05A (± 12)	12,7 A (± 5)

* Duncan analysis groups. (p≤0,05 of significant level).

The theory of variation of tracheid heights depending on tree age was not confirmed in this study. Despite the lower age of the "Y" samples, the tracheid lengths were longer (Figure 6). Which factor that occurs on the road side causes the prolongation of the tracheid lengths should be investigated with further studies.

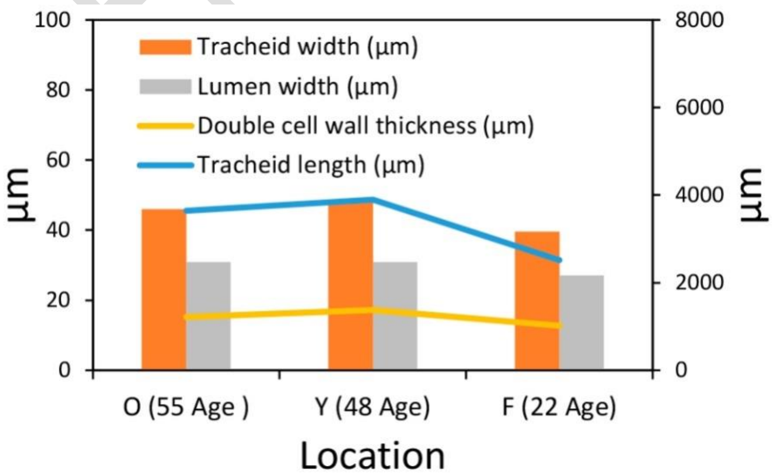

Figure 6: Tracheid measurement results.

The determination of air pollution is made with some studies on the trees on the roadside (Shaheen *et al.* 2016, Wuyts *et al.* 2018). Some studies reported that Mn, Fe, Zn, Cu, Ni, Co, Pb, Ti, V, Cr, As, Zr, Mo, Se, Cd, Pt metals were detected in the tree leaves and outer surfaces of trees implanted near the road (Krupnova *et al.* 2021, Ram *et al.* 2015). Wang *et al.* (2019) reported that foreign particles accumulated 10 times more in the tree leaves on the roadside compared to the trees in the forest. However no more studies were done about the wooden inner parts of the tree. In this study, as seen in the EDAX analysis in Figure 7, the distribution of carbon (C), calcium (Ca), chlorine (Cl) and iron (Fe) elements on the wood surfaces is different.

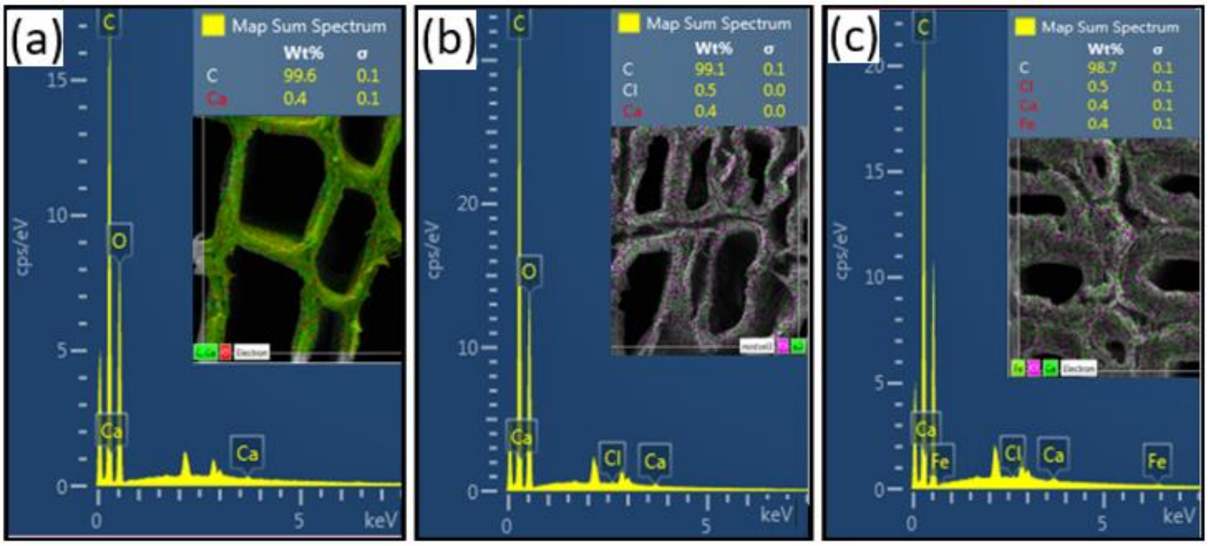

Figure 7: EDX analysis of wood samples, (a) "O" sample, (b) "Y" sample and (c) "F" sample.

While Cl and Fe elements were not found in the sample taken from the forest, it was determined that there were Fe and Cl elements in the sample taken from across the factory. It can be said that environment pollution caused the Fe and Cl elements presence in the "Y" and "F" samples. It is thought that the sodium chloride salt sprinkled on the road surface in winter months to prevent icing causes the presence of Cl in the pine trees growing on the roadside.

Similarly, Kusiak *et al.* (2020) reported that Fe content in linden wood was found in urban agglomeration with the highest environmental stress. Krutul *et al.* (2014) also reported that oak wood taken from polluted environment contains approximately 2 times more Fe than wood taken from uncontaminated environment. However, the authors state that the high Fe content is due to the growing environment, not pollution. Exhaust emissions from vehicles may contain different amounts of Ni, Cu, Zn, Cd and Pb (Samara *et al.* 2003). The presence of these elements was not found in the wood samples taken from the roadside. Accordingly, it can be said that particle filters in vehicles are effective in preventing pollution.

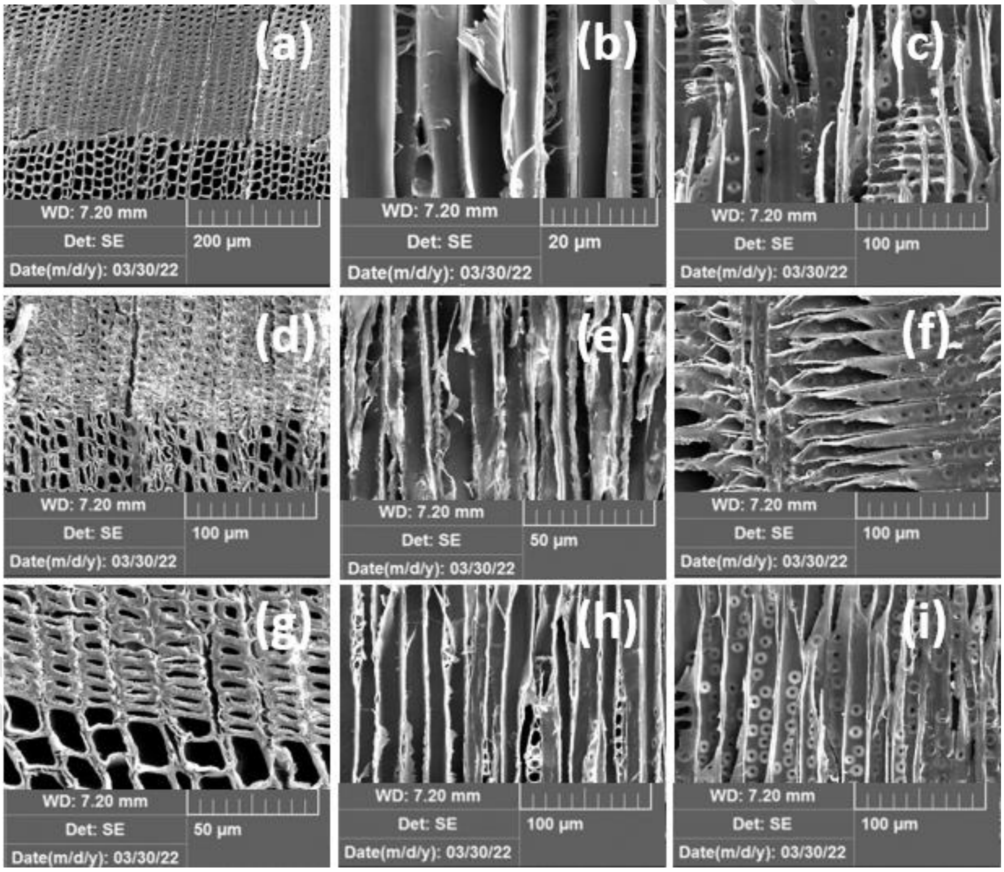

Figure 8: "O" sample cross (a), radial (b), tangential (c) section, "Y" sample cross (d), radial (e), tangential (f) section, "F" sample cross (g), radial (h), tangential (i) section.

When the SEM images were examined, it was determined that the macroscopic tissues of the wood taken from the forest were more uniform (Figure 8a) than the macroscopic textures of the wood taken from the roadside (Figure 8d) and from the factory (Figure 8g). In some studies, (Maher *et al.* 2013, Mitchell and Maher 2009, You *et al.* 2021), particle aggregation can be seen on tree leaves in SEM images, but no particle aggregation was found in the wood part of the tree in this study.

Conclusions

It has been reported in many studies that environmental pollution causes the accumulation of heavy metals in the bark and leaves of trees. However, it has not been investigated whether the wood properties of trees are also affected by air pollution. In this study, physical, mechanical, chemical, and morphological differences between wood samples obtained from black pine (*Pinus nigra* J.F. Arnold) trees growing naturally on the roadside, in front of the factory and in the forest were examined. Overall, it can be concluded,

There is no significant difference in the amount of holocellulose, α-cellulose, and lignin between the trees growing on the roadside and the tree growing in the forest. On the other hand, it was determined that the amount of extractive substance was high in the wood of the tree growing on the roadside.

Trees grown by the roadside have higher density and lower thickness swelling value depending on the growth condition.

The mechanical strength of the tree growing by the roadside is higher due to it shigh density.

The longest and widest tracheids were in the trees growing on the roadside.

Tree samples grown in the forest have a more uniform annual ring formation than grown near the roadside.

Environmental stress causes chlorine in trees growing by the roadside and both chlorine and iron in trees growing near the factory.

Based on the findings, it can be concluded that black pine (*Pinus nigra* J.F. Arnold) is a resistant specie to grow under environmental stress. These trees can be grown near the highway as a barrier to noise and pollution.

Authorships contribution

S. E. K.: Conceptualization, methodology, data curation, formal analysis, writing - original draft. O. K.: Conceptualization, methodology, data curation, formal analysis, writing - original draft. G. T.: Methodology, formal analysis, project administration, writing - review & editing. D. A.: Conceptualization, methodology, data curation, writing - review & editing.

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