The Effects of Microwave and Microwave + Infrared Drying Treatments of *Pinus brutia* and *Picea orientalis* on Water Absorption and Physical Properties

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The goal of this study was to find a way to shorten wood drying time by using microwave and combined infrared + microwave drying methods and to analyze color and gloss changes. Wood samples prepared in three groups with dimensions of 20×20×30 mm were used in moisture tests and 75×5×150 mm were used in color change and gloss measurements, obtained from Red pine (*Pinus brutia*) and Eastern spruce (*Picea orientalis*) woods. The samples were oven dried, dried by microwave, or dried by infrared + microwave drying method. The wood samples all reached the target moisture. Their weight and volume were calculated in accordance with the principles of TS ISO 13061-1. Color change values were determined before and after drying with a portable color reader (Konica Minolta CR-10) device, and gloss measurements were taken with the Gardner brand gloss meter. By microwave drying for 15 min, 4% moisture content was reached in the wood samples, so both time and energy were saved. The moisture content values decreased compared to the whole drying methods. Most color change was observed in the drying methods using infrared for both red pine and eastern spruce.

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INTRODUCTION

Since ancient times, wood has been utilized to satisfy a variety of human needs. It is a natural, renewable, aesthetically pleasing material (Efe and Kasal 2007). However, it needs protection in a number of ways because of its poor resistance to moisture, susceptibility to decay, deformation tendencies, low fire resistance, and susceptibility to color change (Cayir 2017).

Wood material may hold more water than its own weight after being cut from the forest. Before processing the material, the water must be removed from it. For dangerous organisms, wooden materials can serve as a haven and a food source (Altinok, Kureli and Serbest 2009). Wood material needs to be dried at rates suitable for the area of use in order to remove the habitats of hazardous organisms. The moisture content of the fresh wooden material needs to be promptly lowered to a sufficient extent so as to avoid undesirable changes in physical properties (Burdurlu 1995).

As a result, wooden items have imperfections and undesired deformations. It is well known that the drying of wood material can improve its properties in many ways. (Mujumdar 1995). For example, well-dried wood that maintains its degree of dryness resists rot, requires less labour, and produces smoother surfaces after processing (Schiffmann 1987). Hardness, resistance, and adhesive ability are among the attributes that tend to improve as a consequence of an optimized drying regime (Erdin and Bozkurt 2013).

In 1945, a magnetron maker unintentionally found that microwaves (MW) could generate heat. This outcome was swiftly applied to the design of ovens, mostly for the purpose of heating or cooking food and various substances (Terziev, Daniel, Torgovnikov and Vinden 2020). Microwave oven use in domestic kitchens has increased since the early 1970s. These days, sales of ovens exceed 10 million annually in the US alone. Originally utilised in kitchen ovens, microwave energy is now successfully applied in many industrial applications, including heating, drying, hardness, food bleaching, and chemical reactions. This is because, in comparison to conventional drying procedures, the microwave technique offers certain advantages (Saltik 2023).

The electromagnetic radiation known as infrared (IR) has a wavelength that is longer than visible light but shorter than microwaves. The recognized term for technology, infrared, has Latin roots that translate to "under red." One way that infrared rays vary from other types of radiation is that they have a greater capacity to transfer heat (Tiuri, Jokela and Heikkila 1980). The primary characteristic of infrared technology is its ability to heat a product directly without heating the surrounding air, hence eliminating the need for the air to act as a medium. The main energy source is infrared radiation, which has an economic advantage over other heating methods since it transfers heat to surfaces that are directly illuminated by the beam. (Torgovnikov and Vinden 2010). Additional benefits include reducing drying time, being highly energy-efficient, distributing product temperature uniformly during drying, being simple to adjust process parameters, and requiring less space (Ozkoc 2009).

There aren't many infrared and microwave investigations in the wood sector. The goal of this study was to further the research being done on this topic. According to our study's premise, drying wood using a combination of microwave and infrared radiation may be more productive and efficient than traditional drying techniques, and drying ovens can be built to suit this theory.

In this study, red pine and eastern spruce wood samples were dried using oven, microwave, and infrared + microwave technology. Their moisture content were then calculated, color changes and gloss measurements were compared between the wood samples dried using the three different methods.

EXPERIMENTAL

Material

Wood samples from Eastern spruce (*Picea orientalis*) and red pine (*Pinus brutia*) with an average moisture content of 60% were employed in the investigation. The wood came from a company in Izmir, Turkey, that makes wooden products. They began their production process by processing recently cut forest logs. A number of characteristics were taken into account, including their strength, natural color, and flawlessness as well as their parallel fibers, lack of fiber curl, and resistance to fungus and insects. The preparation of test samples was done in compliance with TS ISO 3129 (2021). Following cutting, the samples were sealed tightly with stretch film to keep moisture from evaporating, air contact was closed off, and they were stored in a humid environment until they were dried. Ten samples, each measuring 20 × 20 × 30 mm and 75 × 5 × 150 mm were used for the testing.

Method

Wood drying procedure

Drying processes were carried out at Mugla Sitki Kocman University,

Woodworking Industrial Engineering Laboratories. Three different methods were used as drying methods for all samples. The samples in the first group (oven drying) were dried in a Thermal brand oven at 103 ± 2 °C. Drying time was applied for 24 h. The samples in the second group (microwave drying) were dried in three subgroup in a Bosch brand industrial microwave oven at 900 W power. The subgroups were saved in 5, 10, and 15 min, respectively. Three subgroups of the third group (microwave + infrared) were dried. A Bosch brand industrial microwave was utilized to finish the test setup, and an 80 cm length by 50 cm width Tek-Iz brand industrial infrared device was employed as the IR device. The IR module used MW (medium wave) infrared bulbs, which have a 420 mm filament length and 2.5 KW of power per bulb. The module contained seven infrared bulbs in total.

The drying processes were carried out as shown in Table 1. When IR drying was applied in combination with MW drying, the IR drying was applied first.

Table 1. Groups - Drying Method - Drying Times MW: Microwave / Infrared

Drying methods	Groups	Subgroup	Drying time
Oven	1.Group	-	24 h
Microwave	2.Group	1.Subgroup	5 min
		2.Subgroup	10 min
		3.Subgroup	15 min
IR + MW	3.Group	1.Subgroup	IR 30 min + MW 5 min
		2.Subgroup	IR 1 min + MW 5 min
		3.Subgroup	IR 30 seconds + MW 10 min

Test and Analysis

Moisture content

The moisture content of wood samples was determined according to TS ISO 13061-1 (2019). The moisture content, *W*, of each test piece was calculated as follows,

$$W\% = \frac{(m1-m2)}{m2}\ x\ 100 \quad (1)$$

where m_1 and m_2 are the wet weight before drying (g) and dry weight (g) after drying, respectively.

Color change measurement

Color change values, which are drying quality criteria, were determined before and after drying with a portable color reader (Konica Minolta CR-10) device shown in Fig. 1. In the classification of colors, ISO 2470-1 (2016) (CIELAB-76; International Commission on Illumination) standard were used.

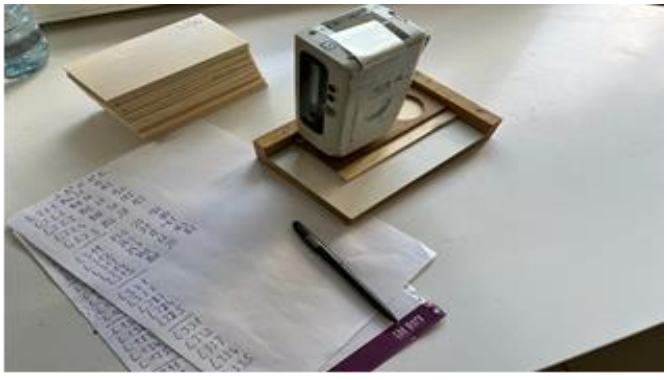


Fig. 1. Portable color reader (Konica Minolta CR-10)

Color changes after drying were calculated using the following formulas.

$$\Delta L* = L*f - L*i$$
$$\Delta a* = a*f - a*i$$
$$\Delta b* = b*f - b*i$$
$$\Delta E* = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \quad (2)$$

where ΔL^*, Δa^* and Δb^* values show the changes between the initial state (i) and the final state (f) of the colors. ΔE^* shows the total color changes occurring in the L^*, a^*, and b^* directions of the colors. The highest value indicates the highest color change.

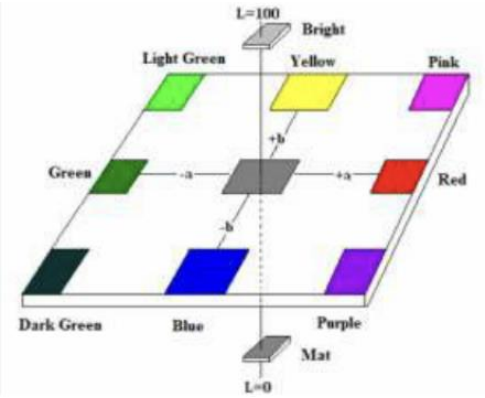


Fig. 2. CIELAB–76 Color space

Gloss measurement

Gloss measurements were taken with the Gardner brand gloss meter shown in Fig. 3. In the gloss meter device, the illumination from the light source is reflected from the surface at a certain angle (20, 60, and 85°) and reaches the sensors on the other side of the device. The ratio of the amount of light reflected on the surface to the amount of light coming from the device source was measured. The resulting numerical values were converted to gloss degree (GU), which is a gloss unit.

Fig. 3. Gloss meter (Gardner)

Statistical Analysis

All data collected within the parameters of the study were statistically analyzed with a 95% confidence level, and analysis of variance was used to show the statistical difference between the factors. The Duncan Test was performed to identify the contributing variables to the variations.

RESULTS AND DISCUSSION

Moisture Content Result

The measured moisture contents of before and after drying and output temperatures of red pine and eastern spruce wood samples are given in Table 2. Before drying, fresh wood samples typically have a moisture level of 60%. Table 2 shows that after drying in an oven at 103 °C for 24 h, the moisture content for red pine wood samples was 4.36%. Following five, ten, and fifteen min of microwave drying, the samples' moisture contents were determined to be 23.7%, 12.4%, and 4.4%, respectively. Red pine samples that had been dried and subjected to the infrared + microwave method were found to have a moisture content of 14% after 1 min, 20.4% after 5 min, and 6.2% after 30 seconds of infrared and 10 min of microwave drying. The moisture content of the eastern spruce wood samples dried in the oven was found to be 4.4%, 23.8%, 10.2%, and 4.4% after 5 min, respectively. On the other hand, the moisture content of samples of eastern spruce dried by infrared + microwave method was determined to be 14.2% after 30 seconds of IR and 5 min of MW, 20.2% after 1 min of IR and 5 min of MW, and 6.30% after 30 seconds of IR and 10 min of MW.

The results of multiple variance analysis for the main factors of wood type, drying method and drying time, and the double and triple interactions of these factors are given in Table 3. Factor A: Wood type (red pine, eastern spruce), Factor B: Drying method (oven, microwave, infrared + microwave), Factor C: Drying time (24 h, 5 min, 10 min, 15 min, 30 s + 5 min, 1min + 5 min, 30 s + 10 min).

Table 2. Wood Samples Output Temperature and Moisture Content of Red Pine and Eastern Spruce Measured after Drying

Drying method	Drying time	Output Temperature (°C)	Red pine (%) moisture content before drying (std. dev.)	Red pine (%) moisture content after drying (std. dev.)	Eastern spruce (%) Moisture content before drying (std. dev.)	Eastern spruce (%) Moisture content after drying (std. dev.)
Oven	24 h	103	60.50 (1.22)	4.35 (0.17)	60.52 (1.65)	4.36 (0.66)
Microwave	5 min	49	60.10 (1.72)	23.72 (0.78)	60.25 (1.11)	23.76 (0.25)
	10 min	94	60.35 (1.18)	12.41 (0.90)	60.40 (0.87)	12.42 (0.96)
	15 min	107	60.55 (1.13)	4.41 (0.50)	60.30 (1.22)	4.45 (0.29)
IR + MW	IR 1 min + MW 5 min	IR 166 / MW 110	60.40 (1.22)	14.14 (0.11)	60.44 (0.66)	14.15 (0.77)
	IR 30 seconds + MW 5 min	IR 144 / MW 95	60.50 (0.66)	20.44 (0.23)	60.45 (1.44)	20.21 (0.73)
	IR 30 seconds + MW 10 min	IR 146 / MW 119	60.22 (1.81)	6.16 (0.19)	60.30 (1.75)	6.30 (0.61)

Note: MW: Microwave. IR: Infrared. The values in parentheses indicate standard deviation (SD)

Table 3. Analysis of Variance Results Regarding the Moisture Values of Two Different Wood Species According to Different Drying Method and Drying Time

Variance source	Sum of squares	Degrees of freedom	Mean of squares	F-value	Statistical significance (P)
Factor A	211.482	1	213.643	11.475	0.001
Factor B	152.215	2	76.107	10.698	0.001
Factor C	885.286	6	147.547	8.838	0.001
A*B	33.988	2	16.994	0.859	0.428
A*C	77.570	6	12.928	0.676	0.659
B*C	189.260	3	63.086	3.387	0.032
A*B*C	1.441	1	1.441	0.076	0.653
Error	1532.610	77	18.618		
Total	26546.349	100			

The primary wood type, drying method, and drying time effects, as well as their interactions, were shown to have statistically significant effects on moisture levels, with a margin of error of $P<0.05$, based on the results of variance analysis. It may be concluded from a study of the F values shown in Table 3 that the primary factor of tree type had a higher impact on moisture levels. Duncan dual comparison tests were performed for the main factors and simultaneous effects in order to determine the significant effects of the main factors and bilateral interactions. Comparison Duncan Test results regarding moisture values according to the drying method are given in Table 4.

Table 4. Pairwise Comparison Test Results According to Drying Method

Drying Method	Average (%)	Homogeneity Group
Oven	9.47	A*
Microwave	13.27	B
Infrared + Microwave	13.53	C

Duncan: 0.050 *Lowest moisture values

It was discovered that the samples dried in the oven had less moisture content than the samples dried by other techniques. The infrared + microwave drying was group C with a value of 13.5%, microwave drying was group B with a value of 13.3%, and oven drying was group A with a value of 9.5% based on homogeneity groups. Table 5 displays the Duncan Test findings for moisture content based on drying time.

Table 5. Pairwise Comparison Test Results Regarding Moisture Values According to Drying Time

Drying Time	Average (%)	Homogeneity Group
Oven 24 h	5.68	A*
MW 15 min	5.98	A
IR 30 seconds + MW 10 min	7.87	A
MW 10 min	13.01	B
IR 1 min + MW 5 min	14.14	B
IR 30 seconds + MW 5 min	20.49	C
MW 5 min	21.33	C

Duncan: 0.050 *Lowest moisture values

The samples dried in the oven for 24 h had a lower moisture content than samples dried for longer periods of time, according to the findings of the Duncan Test of Dual Comparison about drying times and moisture contents.

Homogeneity groups yielded values of 21.3% and 20.5% for 5 min of microwave drying and 30 seconds of infrared plus 5 min of microwave drying, respectively. Group C: infrared radiation for one min plus five min; results were 14.1% and 13.0%, respectively. with values of 7.9%, 6.0%, and 5.7%, respectively, microwave drying and 10 min microwave drying, group B, 30 seconds infrared + 5 min microwave drying, 15 min microwave drying, and oven drying. After being dried in an oven, Group A was also found to have the lowest moisture level.

Color Change Measurement Result

Color changes before and after drying for red pine and eastern spruce wood samples are given in Tables 6 and 7. According to the red pine wood color change table given in Table 6, the most color change, with a value of 8.5, was in the samples dried for 30 seconds with infrared + 10 min with microwave. The second largest color change, with a value of 4.6, was observed in the samples dried for 30 seconds with infrared + 5 min with microwave. The least color change occurred in the samples dried in the oven, with a value of 2.2.

Table 6. Color Measurement Values of Red Pine Wood Samples

Drying Method	Drying Time	Before Drying			After Drying			
		L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*
Oven	24 h	72.4	7.1	26.5	1.5	-1.4	0.9	2.2
Microwave	5 min	74.3	8.7	23.1	3.4	0.2	-2.5	4.2
	10 min	74.8	7.7	24.1	3.9	-0.8	-1.5	4.3
	15 min	74.2	8.1	24.7	3.3	-0.4	-0.9	3.4
Infrared + Microwave	IR 30 s. + MW 5 min	66.3	9.0	25.5	- 4.6	0.5	-0.1	4.6
	IR 1 min + MW 5 min	67.9	9.2	24.1	-3.0	0.7	-1.5	3.4
	IR 30 s. + MW 10 min	62.9	7.1	23.2	-8.0	-1.4	-2.4	8.5

ΔL^*, Δa^* and Δb^* are the values for the initial state (i) and final state (f) of the colors, ΔE^* is the total color changes occurring in the L, a, and b directions of the colors.

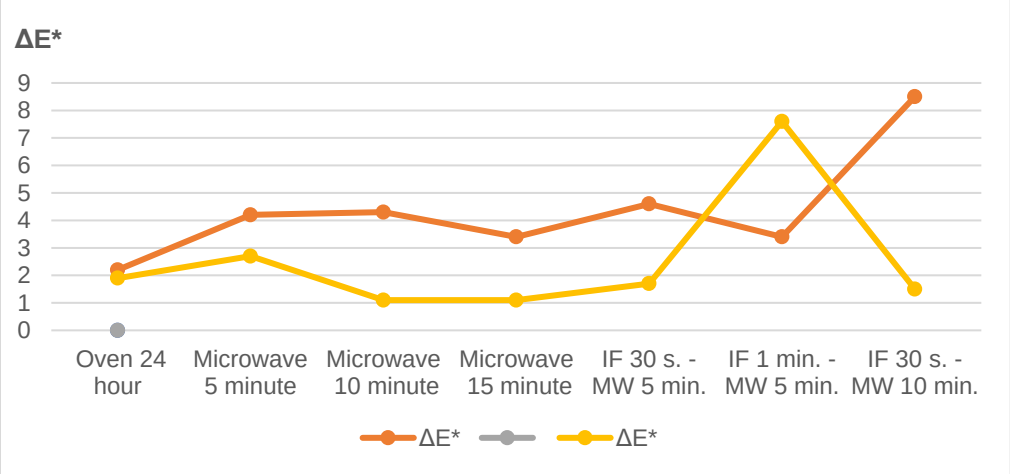
Table 7. Color Measurement Values of Eastern Spruce Wood Samples

Drying Method	Drying Time	Before Drying			After Drying			
		L^*	a^*	b^*	ΔL^*	Δa^*	Δb^*	ΔE^*
Oven	24 h	84.0	2.1	20.7	-0.2	0.3	1.9	1.9
Microwave	5 min	84.1	3.5	20.9	-0.1	1.7	2.1	2.7
	10 min	83.7	2.8	18.8	-0.5	1.0	0.0	1.1
	15 min	84.3	2.9	19.1	0.1	1.1	0.3	1.1
Infrared + Microwave	IR 30 s. + MW 5 min	82.9	2.7	19.4	-1.3	0.9	0.6	1.7
	IR 1 min + MW 5 min	80.5	5.6	24.3	-3.7	3.8	5.5	7.6
	IR 30 s. + MW 10 min	84.0	2.4	20.2	-0.2	0.6	1.4	1.5

ΔL^*, Δa^* and Δb^* are the values for the initial state (i) and final state (f) of the colors,

ΔE^* is the total color changes occurring in the *L*, *a*, and *b* directions of the colors. Looking at the color change values given in Table 7. For eastern spruce wood, the most color change with a value of 7.6 occurred in the samples dried for 1 min with infrared + 5 min with microwave. The lowest color change, with a value of 1.1, was observed in the samples dried in microwave for 15 min.

The color change values of the samples dried in the oven were close to each other, but differed for other drying methods. The largest color change difference was in the samples dried for 30 seconds with infrared + 10 min with microwave.



Note: Red color: Red pine; Yellow color: Eastern spruce

Fig. 5. Pairwise comparison color change measurements for red pine and eastern spruce

Gloss Measurement Result

For red pine and eastern spruce wood samples, gloss measurement values according to drying method, time and 20°- 60°- 85° angles are given in Table 8.

Table 8. Gloss Measurement Values of Red Pine and Eastern Spruce Wood Samples

Drying Method	Drying Time	Wood Type	20º	60º	85º
Oven	24 h	Red pine	0.8	3.0	0.9
Microwave	5 min		0.9	3.2	1.1
	10 min		0.9	3.6	1.4
	15 min		1.0	3.7	1.1
Infrared + Microwave	IR 30 s. + MW 5 min		0.8	3.0	0.9
	IR 1 min + MW 5 min		0.8	3.5	1.4
	IR 30 s. + MW 10 min		0.8	3.1	2.1
Owen	24 h	Eastern spruce	1.6	6.7	3.0
Microwave	5 min		1.6	6.3	2.3
	10 min		1.6	6.5	2.3
	15 min		1.4	5.8	2.0
Infrared + Microwave	IR 30 s. + MW 5 min		1.5	6.3	3.0
	IR 1 min + MW 5 min		1.2	5.8	4.2
	IR 30 s. + MW 10 min		1.5	6.5	2.7

For red pine wood samples, the gloss measurement values were close to each other, with the samples dried with microwave for 15 min giving the highest value, with 1.1 and 3.7 according to the angles of 20° and 60°, respectively. The samples dried for 30 seconds with infrared + 10 min with microwave gave the highest value in gloss measurement according to an 85° angle. For eastern spruce wood samples, the values were close to each other. Samples dried with microwave for 10 min at 20° gave the highest value, samples dried with owen drying for 60° gave the highest value, and samples dried with 1 min infrared + 5 min microwave for 85° gave the highest value.

CONCLUSIONS

In this study, moisture content, color change and gloss measurement values of eastern spruce and red pine wood samples dried by oven, microwave and combination of infrared + microwave methods were examined.

1. For both kinds of wood products, the necessary target moisture values were rapidly decreased as the microwave drying time increases. The moisture values were obtained in 24 h using the oven drying method and only 15 min using the microwave drying method.
2. After the 1 min infrared drying time, burning happened to the samples in the infrared + microwave drying group.
3. The greatest color change occurred in the drying methods using infrared for both red pine and eastern spruce wood samples. The reason for this is that infrared drying is superficial. Burning occurred in wood samples as a result of infrared drying for more than 30 seconds.
4. There was the least color change in the samples dried in the microwave for 15 min, and the color change was not much in the samples dried in the oven, although it had the longest drying time compared to other drying methods.
5. The red pine and eastern spruce wood samples dried with microwave for 15 min had the highest gloss values at angles of 20 and 60°, and at the angle of 85°, the samples dried with infrared 30 seconds + microwave for 10 min gave the highest gloss value. It was observed that the samples dried in the oven generally gave the lowest values in both red pine and eastern spruce wood samples.

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