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Research Article

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Determination of Some Physico-Mechanical Properties of Silver Linden (*Tilia tomentosa* Moench) Plant

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Abstract The aim of this study is to investigate the physico-mechanical properties of the lime tree (*Tilia tomentosa* Moench) during two different harvesting periods (H1 and H2). The focus is on the flower, bract and stem parts of the plant. The moisture content, mechanical strength, colour characteristics and friction properties of the plant were evaluated. The moisture content of the materials was found to be 69.2% in H1 and 71.5% in H2. The flower to bract ratio was 71.36 ± 5.65% in H1 and 74.49 ± 4.19% in H2, while the bract to stem ratio was 36.80 ± 3.00% in H1 and 37.09 ± 4.56% in H2. These ratios indicate that the bract-stem ratio is higher in H2. Mechanical tests showed that the maximum force and rupture force were higher in the H2 period, with values of 9.21 N and 6.86 N respectively. The maximum stress value was found to be 8.27 N mm-2 in the H2 period, showing stronger mechanical properties. The energy required to reach maximum stress and to break was also higher in H2, with values of 0.008 J and 0.009 J respectively. Colour measurements showed that the bract and flower parts were lighter in colour in the H2 harvest period. The a-value in the bract parts was more negative in H2, indicating a greener tone, while the b-values were higher, indicating a more yellow tone. The static friction coefficient was found to be highest (1.03) in the H1 period with rubber material and lowest (0.60) in the H2 period with PVC material. The study shows that plants harvested in the H2 period have stronger and more durable physico-mechanical properties, making them more suitable for industrial applications. This study offers new perspectives for increasing the usability of silver lime in industrial applications.

Keywords silver linden, physico-mechanical properties, industrial application, agricultural mechanization

1. Introduction

Silver lime (*Tilia tomentosa* Moench) is a broad-leaved tree species that can reach heights of 30-40 meters and grows naturally in Turkey. This species typically spreads in forested areas, either as solitary trees or in small groups [1]. Linden flowers, classified as non-wood forest products, have traditional and widespread uses. In Turkey, there are four naturally occurring linden taxa: *Tilia tomentosa* Moench, Tilia cordata Miller, Tilia platyphyllos Scop., and Tilia rubra DC subsp. caucasica (Rupr.) [1,2]. Silver lime (*Tilia tomentosa* Moench) is a significant tree species of the Tilia genus and is widely present in the forest ecosystems of Turkey. The Tilia genus comprises approximately 45 species that naturally grow in the temperate regions of the Northern Hemisphere, among which *Tilia tomentosa* holds significant economic and ecological importance [3,4].

Tilia tomentosa is widely used in traditional medicinal practices due to its spasmolytic, diuretic, and sedative effects, particularly attributed to its flavonoid content, essential oils, and mucilage components [4]. Among the four *Tilia* species naturally found in Turkey, *Tilia tomentosa* is also favored as an ornamental plant in parks and gardens. The fragrant and decorative flowers of linden trees hold an important place in urban landscaping [5]. In the forests of our country, it is widely harvested for its therapeutic and calming properties [2].

In recent years, studies on the physico-mechanical properties of *Tilia tomentosa* have increased. One study identified its morphological characteristics, volatile compounds, their ratios, and molecules, highlighting its potential applications in the medical, cosmetic, and industrial fields [6]. These studies investigate the biological properties of the plant as well as its applicability in various industrial applications. For instance, the wood of the linden tree is favored in furniture and other wooden products due to its light weight and workability. Additionally, the bark and other by-products of these trees are also utilized in various sectors [3].

Since silver lime can reach heights of up to 40 meters [7], flower harvesting is typically performed by cutting thick branches, a method that can cause significant damage to the tree [8]. It is emphasized that cultivated medicinal plants should be preferred over those harvested from natural habitats. This is important for ensuring production in the quantity and quality demanded by the market, as well as for maintaining the current situation. However, it is not possible to obtain sufficient quantities and quality of products from natural habitats using current methods [1]. The harvesting techniques employed by forest villagers when collecting linden flowers have led to degradation in forest areas over time, creating a negative scenario regarding the efficiency of resource utilization [2].

This research aims to determine some physico-mechanical properties of Tilia tomentosa, thereby expanding the areas of utilization for this valuable tree and promoting its more efficient use. The conducted studies indicate that the increased use of *Tilia tomentosa* in urban landscaping is attributed to its high drought and pest tolerance, and these characteristics are directly related to the plant's physico-mechanical structure [3].

In this context, a detailed examination of the physico-mechanical properties of *Tilia tomentosa* will not only contribute to the scientific literature but also facilitate its more effective use in various industrial and environmental applications.

2. Materials And Methods

The material for the study consists of silver lime trees located in the Çünür district of Isparta, on the campus of Isparta University of Applied Sciences. The experimental material includes the flowers, bracts, and petioles of the silver lime (*Tilia tomentosa* Moench) (Figure 1). Flower sampling was conducted in June 2023. Flowers were collected from the outer sections of the crown, at a height of 2-4 meters from the ground, with a minimum of 400 grams of linden flowers gathered from each tree. The harvested flowers were immediately placed in bags, which were sealed to prevent moisture loss. After weighing the samples brought to the laboratory, they were placed on shelves for drying in the shade.

Figure 1. *Silver lime (Tilia tomentosa Moench) plant.*

The drying rates, flower-bract ratio, and bract-branch ratio of the plant were determined during two different harvesting periods (H1 and H2), and physical properties such as weight, moisture, colour, surface area, and friction were evaluated. This method aims to thoroughly investigate the physical and mechanical properties of various parts of the silver lime (*Tilia tomentosa* Moench) plant.

An universal testing machine operating in the tensile and compressive force directions was used for cutting and shearing tests. The flower rupture force was determined by applying a pulling force along the plant stem axis using jaws that grasped the branch from which the flower originated. In the experiments, the cutting operation was executed via the linear vertical movement of the movable upper blade, operating at a speed of 200 min-1 against the fixed plant stem.

In the measurements of the colour scale values L, a, and b*, the L* value represents the level of lightness or darkness (where whiteness increases from 0 to 100). The a* value indicates the colour transition from green to red (+a represents red, while -a represents green), and the b* value reflects the colour transition from yellow to blue (+b indicates yellow, while -b indicates blue) [9-10]. Measurements were conducted by placing the materials in a sample holder and ensuring that the device made direct contact with the surface of the material. Each measurement was repeated five times to obtain average values.

Frictional forces were measured by pulling the box across the surfaces. The specially designed test mechanism for measuring frictional properties consists of three components: the product container, the friction surface, and the data measurement system (Figure 4). Four different surface materials (rubber, glass, composite, and PVC) were used for the determination of static frictional forces. The bottom part of the box, where the test materials are placed, has been left open, and a wheeled mechanism has been added to prevent direct contact with the surface. This box measures 140 × 200 × 300 mm.

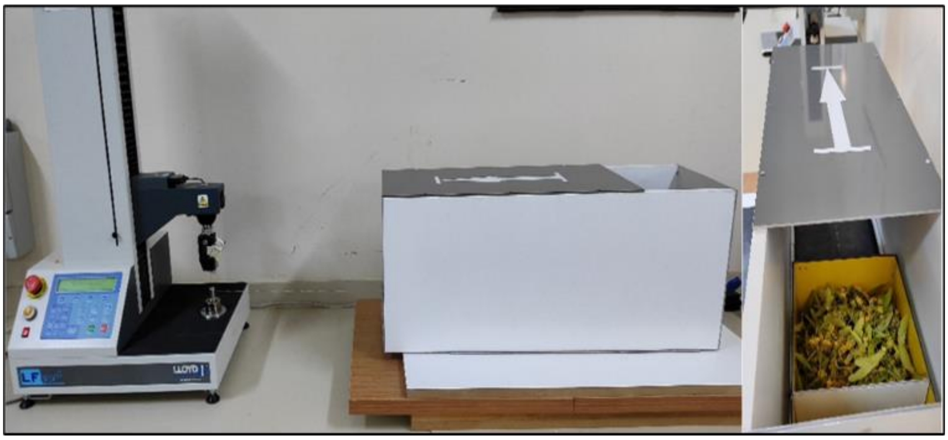

Figure 2. *The mechanism used for determining frictional properties*

The friction data from tests conducted on each surface material were automatically recorded by the device in the form of force-time graphs. The pulling operation was performed over a distance of 70 centimeters. The maximum force value measured by the device was considered as the static frictional force. The average of 10 measurements recorded by the device was calculated as a single replicate [11-12]. The friction experiments were conducted at a constant speed of 20 mm/s during two different harvesting periods.

3. Results and Discussions

The moisture content values of the materials from the linden plant were determined to be 69.2% and 71.5% on a wet basis for the H1 and H2 harvesting periods, respectively. The weights of the materials (bracts) were measured to be an average of 0.38 ± 0.14 g for H1 and 0.77 ± 0.21 g for H2, while the diameter of the plant stem was measured to be an average of 1.13 ± 0.19 mm for H1 and 1.21 ± 0.17 mm for H2.

In this study, the flower-bract ratios and bract-branch ratios of the silver linden plant during the H1 and H2 harvesting periods were determined. The flower-bract ratio was found to be 71.36 ± 5.65 for the H1 harvesting period, while for the H2 harvesting period, it was found to be 74.49 ± 4.19. The bract-branch ratios were measured at 36.80 ± 3.00 for the H1 harvesting period and 37.09 ± 4.56 for the H2 harvesting period. These data indicate the effects of different harvesting periods on the morphological characteristics of the plant and provide important insights for its industrial use.

In the flower rupture tests, the flowers were detached from the plant branch, which was secured using jaws, at a pulling speed of 200 mm/min with the aid of a moving platform. The obtained rupture parameters were recorded on a computer. The average values of the maximum force, rupture force, deformation, stress at maximum load, toughness, energy up to maximum load, and energy expended until rupture, as obtained from the pulling tests are presented in Table 1. The variations in these properties of the linden plant according to the harvesting period were found to be statistically significant at the $p<0.05$ level, and letter grouping was performed based on the level of significance.

Table 1. The rupture parameters of the linden bract from the stem

Harvesting Period	Maximum Force (N)	Rupture Force (N)	Stress at Maximum Load (N mm^{-2})	Energy up to Maximum Load (J)	Energy until Rupture (J)	Deformation (mm)	Stress at Rupture point (N mm^{-2})
H1	6.59b (±1.50)	4.70^{b} (±2.46)	7.07^{b} (±2.86)	0.006^{b} (±0.002)	0.007^{b} (±0.002)	3.46^{b} (±1.65)	5.09^{a} (±3.28)
H2	9.21a (±1.95	6.86^{a} (±3.26)	8.27^{a} (±2.37)	0.008^{a} (±0.002)	0.009^{a} (±0.003)	2.18^{a} (±0.46	6.26^{a} (±3.32)

In the H2 harvesting period, the maximum force and rupture force values were found to be higher than those in H1, recorded as 9.21 N and 6.86 N, respectively. It is observed that the bracts in the H2 period are more resistant to rupture. The stress at maximum load during the H2 period was also found to be 8.27 N mm^2, indicating that the bracts have a more durable structure in this period. The energy required to reach the maximum load and the energy until Rupture point were both higher in the H2 period, recorded as 0.008 J and 0.009 J, respectively. The deformation value in the H1 period was higher compared to H2, measured at 3.46 mm. The stress at Rupture point was also highest in the H2 harvesting period, determined to be 6.26 N mm^2.

The bracts harvested during the H2 period are observed to be stronger and more durable in terms of physical and mechanical properties

The data related to colour characteristics are presented in Table 2. According to the obtained data, it has been determined that the colour characteristics vary according to the harvesting periods.

Table 2. Colour characteristics of the linden plant

	Bracts		Flower	
Harvesting Period	**H1**	**H2**	**H1**	**H2**
L(Lightness/Darkness)	48.52 ±8.43	58.02±6.01	52.26±9.05	53.73±10.65
A (Green-Red)	-3.49±6.23	-8.66±4.84	6.01±2.54	1.60±2.61
B (Blue-Yellow)	26.54±3.50	35.74±4.42	30.72±5.36	25.42±3.96

Upon examining the table, an increase in the L values of both bracts and flowers has been observed during the H1 and H2 harvesting periods based on the determined colour values for the linden plant. Notably, in the bract sections, the L value increased from the H1 to the H2 period, indicating that lighter-coloured bract samples were present in the H2 period. A similar increase in the L value was also observed in the flower sections; however, the increase was not as pronounced as that of the bracts. In the bract sections, a value became more negative in the H2 period compared to the H1 period, suggesting that the bracts were greener in the H2 period. Conversely, in the flower sections, a value decreased during the H2 period, resulting in a reduction of reddish tones and a shift towards a greener hue. Additionally, the b values for both bracts and flowers increased in the H2 period compared to the H1 period. This increase indicates that the plants exhibited more yellow tones in the H2 period, with a particularly significant rise in the b value for the bract sections.

There are significant colour differences between the two harvesting periods. It has been observed that the bracts and flower sections harvested in the H2 period exhibit lighter, greener, and more yellow tones. The values of the static friction coefficient for the bracts of the linden plant are presented in Table 3.

Table 3. The values of the static friction coefficient for the linden plant.

	Static friction coefficient (μ_s)	
Harvesting Period	**H1**	**H2**
Rubber	0.84	1.03
Glass	0.82	0.59
Composite	0.60	0.75
PVC	0.62	0.60

The static friction coefficient values for the bracts of the linden plant were found to be highest in tests conducted with rubber material, reaching 1.03 during the H1 harvest period. The lowest values were obtained during the H2 harvest period. Similar values were obtained in tests with glass and PVC materials, recorded at 0.59 and 0.60, respectively.

In the shade trials for the linden plant, the natural drying duration continued for 51 hours. The ambient temperature values in the shade varied depending on environmental conditions. At the end of the trial, the average air temperature in the shade was measured to be 30.5 °C. The drying process was continuous, and the final moisture content of the dried plant material decreased to 33.4%.

4. Conclusions

In this study, the physico-mechanical properties of silver linden (*Tilia tomentosa* Moench) were examined in detail during two different harvest periods (H1 and H2). The moisture content values during the harvest periods were found to be 69.2% for H1 and 71.5% for H2, based on a wet basis.

In the H1 harvest period, the flower-bract ratio was determined to be 71.36 ± 5.65%, while in the H2 harvest period, this ratio was found to be 74.49 ± 4.19%. The bract-stem ratio was measured as 36.80 ± 3.00% in the H1 harvest period and 37.09 ± 4.56% in the H2 harvest period. These data indicate that the bract and stem ratios are higher in the H2 harvest period.

In the H2 harvest period, the maximum force (9.21 N) and rupture force (6.86 N) were found to be higher compared to the H1 period. This indicates that the bracts are more resistant in the H2 period. Additionally, the values for maximum stress (8.27 N mm^{-2}), energy until maximum load (0.008 J), and energy until failure (0.009 J) were also found to be higher in the H2 period compared to the H1 period. This suggests that the mechanical properties of the plants are stronger in the H2 period.

In the colour measurements, plants from the H2 harvest period were observed to exhibit lighter, greener, and yellower tones in both the bract and flower parts. The highest values for the static friction coefficient were obtained from tests conducted with rubber materials, while the lowest values were obtained from tests with PVC materials.

Due to the stronger and more durable physico-mechanical properties of the plants in the H2 harvest period, it is recommended to prefer this period for industrial use and efficiency.

A detailed examination of the physico-mechanical properties of silver lime will enable its more effective and efficient use in furniture, cosmetics, medical, and other industrial fields. The results of this study contribute to the understanding of how the physico-mechanical properties of silver lime change across different harvest periods. The obtained data provides significant insights for expanding the usage areas of this valuable tree and utilizing it more efficiently.

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