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Utilizing Alkali Pre- Treated Banana Waste in Sustainable Particleboard Manufacturing

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Anahtar Kelimeler

Atık Kullanımı
Alkali Ön İşlem
Sürdürülebilir Malzemeler
Yongalevha

Graphical/Tabular Abstract (Grafik Özet)

In this study, the board production performance of particles obtained from the leaves and stems of the waste banana plant was examined. Alkaline pre-treatment was applied to the particles to examine the effect on usage performance before production. / Bu çalışmada, atık halde bulunan muz bitkisinin yaprak ve gövdelerinden elde edilen yongaların levha üretim performansı incelenmiştir. Yongalara çalışma öncesi kullanım performansı etkisini incelemek için alkali ön işlem uygulanmıştır.

Figure A: *Board production process /* ***Şekil A:*** *Levha üretim süreci*

Highlights (Önemli noktalar)

- *It attracts attention with its alternative raw material source and usage possibilities. / Alternatif hammadde kaynağı ve kullanım olanakları bakımından dikkat çekmektedir.*
- *The performance of the boards obtained from banana waste reveals their usability. / Muz atıklarından elde edilen levhaların performansı kullanılabilirliğini ortaya koymaktadır.*
- *The effect of alkali pretreatment application on the boards is clearly seen. / Alkali önişlem uygulamasının yongalar üzerine etkisi açıkça görülmektedir.*

Aim (Amaç): *The aim of this study is primarily to evaluate banana plant wastes that are waste and not used in any way. It is to obtain added value by producing particleboard from waste materials. Additionally, performance differences can be achieved through alkaline pre-treatment application. / Bu çalışmadaki amaç öncelikle atık halde bulunan ve her hangi bir şekilde kullanılmayan muz bitkisi atıklarının değerlendirilmesidir. Atıklardan yongalevha üreterek katkı değer elde etmektir. Ayrıca, alkali ön işlem uygulaması ile de performans farklılıkları oluşturmaktır.*

Originality (Özgünlük): *In this study, alkaline pre-treatment was applied to waste banana plant particles before board production. In this way, its effects on board performance were added to the literature. / Bu çalışmada, atık muz bitkisi yongalarına levha üretim öncesi alkali ön işlem uygulaması yapılmıştır. Bu sayede, levha performansı üzerine etkileri literatüre eklenmiştir.*

Results (Bulgular): *There have been changes in the performance of the boards produced with alkaline pretreatment applied at different concentrations. The ideal concentration rate was found to be 1%. There were also notable differences in surface properties. / Farklı derişimlerde uygulanan alkali ön işlem ile üretilen levhaların performanslarında değişimler olmuştur. İdeal derişim oranının %1 olduğu görülmüştür. Yüzey özelliklerinde de dikkate değer farklılıklar gerçekleşmiştir.*

Conclusion (Sonuç): *It reveals the feasibility of using banana waste as an alternative raw material source in particleboard production. / Muz atıklarının yongalevha üretiminde alternatif bir hammaddde kaynağı olarak kullanılmasının uygulanabilirliğini ortaya koymaktadır.*

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Abstract

Banana (*Musa acuminata* colla) cultivation and trade are widespread across various regions and countries globally. Nonetheless, substantial quantities of waste, primarily comprising leaves and stems of the banana plant, are annually disposed of into the environment post-harvest. This study aims to highlight this issue and propose an alternative solution in response to the escalating demand for raw materials. To this end, alkaline pretreatment was administered to particles derived from banana waste leaves and stems using NaOH solutions at concentrations of 1%, 3%, and 5%, followed by board production. Results indicate that water absorption (WA) and thickness swelling (TS) values of the produced boards increased with alkaline treatment. However, the mechanical properties stipulated in the TS-EN 312 (2012) standard were satisfactorily achieved with 1% NaOH treatment, while higher concentrations adversely affected internal bond strength (IB), modulus of elasticity (MOE), and modulus of rupture (MOR). In the surface properties tests of the boards, increasing the alkali concentration decreased values of the surface roughness and the contact angle. Overall, the findings suggest the viability of utilizing banana waste as an alternative resource.

Sürdürülebilir Yongalevha Üretiminde Alkali Ön İşlem Uygulanmış Muz Atığının Kullanımı

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Öz

Muz bitkisi (*Musa acuminata* colla) dünyanın birçok bölgesinde ve ülkesinde üretimi ve ticareti yapılmaktadır. Bununla birlikte, her yıl muz bitkisinin yaprak ve saplarından oluşan önemli miktarda atık, hasat sonrasında çevreye atılmaktadır. Bu çalışma, bu konuyu vurgulamayı ve artan hammadde talebine yanıt olarak alternatif bir çözüm önermeyi amaçlamaktadır. Bu amaçla, atık halde bulunan muz yaprakları ve gövdelerinden elde edilen yongalara, %1, %3 ve %5 derişimlerde NaOH çözeltileri kullanılarak alkali ön işlemi uygulanmış ve ardından levha üretimi gerçekleştirilmiştir. Üretilen levhaların su alma (SA) ve kalınlığına şişme (KŞ) değerleri alkali işlem derişimi arttıkça yükselmiştir. TS-EN 312 (2012) standardında beklenen mekanik özelliklere %1'lik NaOH işlemi grup örneklerinde ulaşılmıştır. Derişimin daha fazla artması, eğilmede elastikiyet modülü (EM), eğilme direnci (ED) ve yüzeye dik çekme direnci (YDÇD) değerlerinin düşmesine neden olmuştur. Levhaların yüzey özellikleri testlerinde ise, alkali derişiminin artması yüzey pürüzlülüğünü azaltmış, temas açısını düşürmüştür. Bu çalışmanın sonuçları genel olarak, muz atıklarının alternatif bir kaynak olarak kullanılmasının uygulanabilirliğini ortaya koymaktadır.

1. INTRODUCTION (GİRİŞ)

Wood material, which has an important place in the social, economic and technological development of humanity, is decreasing day by day. It is having difficulty meeting the increasing demand. Increasing demand for forest products has put the forest industry in search of alternative raw material sources. At present, wood costs are generally on the rise due to surpassing demand over supply. So, non-wood lignocellulosic resources, particularly agricultural wastes, are currently being utilized or introduced as feedstock for pulp, paper, and composite production in the wood industry [1-7].

In the 21st century, the importance of clean production and sustainability issues has increased. Therefore, there has been greater focus in the particleboard industry on environmental factors such as sustainable forest management practices

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and recycling processes [8-10]. Hence, assessing the viability of employing diverse types of agricultural residues in the production of composites, contingent upon the characteristics of the raw materials, holds significant importance. Particleboard is a type of board produced naturally or synthetically, wood-based, in different forms. This versatile material finds applications ranging from exterior facades of architectural structures to interior coverings, as well as in furniture and packaging industries [11-14].

Different methods are used for lignocellulosic materials to increase usability efficiency in particle board production. Alkali pretreatment is one of these methods. Alkali treatment is a commonly employed method to alter the surface characteristics of particles and fibers, thereby augmenting the presence of reactive OH groups in the material. This process facilitates enhanced adhesion between particles and fibers, consequently improving the mechanical properties of composites. Sodium hydroxide (NaOH) serves as a frequently utilized chemical reagent for treating both wooden and non-wooden materials to improve the mechanical properties [15-20].

The global banana industry spans over 130 countries, encompassing more than 5 million hectares of plantation and yielding a total production of 96 million tons, as reported by the FAO in 2018. Notably, over 80% of the bananas harvested are designated for local consumption within the respective countries of cultivation. With international trade of approximately $9 million annually, it benefits many developing countries [21-22]. Banana fibers, originating as agricultural waste from banana cultivation, are abundantly found in tropical regions worldwide. These fibers are typically categorized as lignocellulosic materials, characterized by helically woven cellulose micro-fibrils embedded within an amorphous matrix composed of lignin and hemicelluloses [23-24].

Banana plantations worldwide generate substantial amounts of banana waste, including banana pseudostems, which are often left to decompose, releasing significant quantities of methane gas and carbon dioxide. The emissions resulting from burning this waste have a detrimental impact on the environment, potentially exacerbating global warming annually. On average, every ton of banana waste emits half a ton of carbon dioxide per year. Hence, there is a pressing need to explore the potential for converting this waste into a valuable resource by extracting fibers from bananas. Failure to address this issue could lead to a significant disposal problem in the future [25-28].

This study explores the producing novel boards utilizing waste banana stems and leaves through a straightforward process technology, aiming to assess its effectiveness. For this purpose, collected banana leaves and stems were shredded and turned into particles. Alkaline pre-treatment was applied to the particles with NaOH solutions. The effect of alkali pretreatment application on the physical, mechanical and surface properties of the board was investigated.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

2.1. Material (Materyal)

Banana waste materials (leaves and stem) were collected from Anamur-Mersin region of Türkiye thrown into the environment as post-harvest waste in the summer of 2023. The collected waste materials were ground in a hammer mill to a size that could pass through 1-3 mm sieves. After grinding, the chips were dried until ready. Then, the resulting particles were spread out and air-dried for a period of 4 weeks. The hardener (Ammonium chloride) and resin (Urea formaldehyde) utilized in the study were procured from Ayteks Chemical Industry Ltd. Denizli/Türkiye. The hardener and resin used in production are products that have standard features and are widely used in the industry [17].

The particles used in the study were stored in NaOH solutions at concentrations of 1%, 3% and 5% (w/v) at room temperature for 24 hours. After treatment, they were thoroughly rinsed with water, kept in a 10% acetic acid solution to neutralize residual NaOH and then rinsed with water again. The rinsed fibers were spread and air dried.

2.2. Method (Metot)

Particleboard production was carried out by following the production stages in [17]. Compliance with the TS-EN 312 (2012) standard was ensured during sizing and conditioning phases [29]. Physical properties of the produced boards were assessed through water absorption (WA) and thickness swelling (TS) tests, while mechanical properties were evaluated through internal bond strength (IB), modulus of elasticity (MOE), and modulus of rupture (MOR) tests. Sample preparation and testing procedures adhered to relevant standards, namely TS-EN 319 (1999), TS-EN 310 (1999), and TS-EN 317 (1999) [30-32]. Surface roughness measurements were performed according to DIN 4768 (1990) standard [33], and water contact angle measurements followed the same methodology as per DIN 4768 (1990) standard [34]. Consistently, identical equipment as detailed in [35] was utilized for both surface properties assessments.

SPSS® 20.0 for Windows® software was conducted for statistical analysis of the study's results. The data underwent analysis of variance (ANOVA) testing. In instances where the ANOVA test indicated statistical differences, a Duncan test was employed to identify distinct groups (IBM Corp., Armonk, NY, USA).

3. RESULTS (BULGULAR)

The physical properties of boards produced from untreated and treated banana particles are summarized in Table 1. Utilizing ANOVA analysis, a statistically significant distinction was observed between the untreated and treated groups concerning the physical properties of the specimens under investigation. Following the application of the Duncan test, four homogeneous clusters emerged within each dataset corresponding to TS-2, TS-24, WA-2, and WA-24.

Table 1. Physical properties of the boards produced from treated and untreated banana particles (Alkali ön işlem görmüş ve görmemiş yongalardan elde edilen levhaların fiziksel özellikleri).

Sample Type	WA-2 h	WA-24 h	TS-2 h	TS-24 h
Control	36.67 (2.57)[1] a[2]	58.05 (4.71) a	16.22 (2.84) a	26.45 (1.58) a
1% NaOH	45.71 (3.84) b	71.12 (5.04) b	23.61 (2.25) b	35.52 (2.05) b
3% NaOH	59.66 (4.62) c	84.39 (6.34) c	29.83 (1.93) c	41.78 (2.14) c
5% NaOH	74.24 (5.44) d	96.58 (6.07) d	34.18 (2.11) d	44.91 (2.86) d

* [1]: Standard deviation, [2]: Groups defined by different letters in each column according to the Duncan test (for D_0, WA (2 and 24 h), TS (2 and 24 h) and WPG $p<0.01$). N:20

It was noted that the values for WA-2, WA-24, TS-2, and TS-24 increased with the escalation of NaOH solution concentrations at 1%, 3%, and 5% during alkali modification. Research indicates that with higher concentrations of NaOH in the particles or fibers of lignocellulosic-based products subjected to alkali treatment, there is a decrease in the quantity of hydrophobic extractive substances and lignin. Although the quantity of hydrophilic hemicellulose diminishes post-treatment, there is a proportional increase in the content of hydrophilic cellulose [15, 17, 36-38].

The mechanical properties of boards fabricated from untreated and treated banana particles are detailed in Table 2. A significant difference was detected in the mechanical characteristics of the test samples between the treated and untreated groups, as per the ANOVA analysis. Following the application of the Duncan test, three homogenous groups were delineated for each of the variables: MOR, MOE, and IB.

Table 2. Mechanical properties of the boards produced from treated and untreated banana particles (Alkali ön işlem görmüş ve görmemiş yongalardan elde edilen levhaların mekanik özellikleri).

Sample Type	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)
Control	9.51 (0.68)[1] b[2]	1483 (93) b	0.25 (0.04) b
1% NaOH	11.87 (1.14) a	1726 (138) a	0.30 (0.04) a
3% NaOH	9.43 (0.32) b	1439 (105) b	0.23 (0.03) b
5% NaOH	7.21 (0.58) c	1174 (114) c	0.17 (0.05) c

[1]: Standard deviation, [2]: Groups defined by different letters in each column according to the Duncan test (for MOR, MOE, and IB $p < 0.05$); N=10

In comparison to boards manufactured with untreated particles, those crafted with 1% NaOH-treated particles exhibited elevated MOE, MOR, and IB values. Particleboards treated with 3% NaOH displayed mechanical properties that did not significantly differ from untreated boards. However, particleboards treated with 5% NaOH exhibited significantly lower mechanical properties. The study's findings indicate that only boards manufactured with 1% NaOH treated particles fulfilled the minimum requirements for MOE, MOR, and IB values (should have minimum values of 1600 N/mm2, 10 N/mm2 and 0.24 N/mm2 respectively) specified for interior fitment particleboards (including furniture) and general-purpose applications in dry conditions, as outlined in TS-EN 312, 2012 [29]. However, applying more than 1% NaOH treatment resulted in a decline in mechanical property values. Lignin serves as a natural adhesive, contributing to robust adhesion and thereby enhancing bonding and dimensional stability. However, the application of alkali pretreatment leads to a reduction in lignin content, potentially compromising adhesion and internal bonding. Research indicates that exceeding a 1% NaOH concentration in lignocellulosic fibers can induce fiber weakening, ultimately resulting in diminished mechanical properties [38-40].

Table 3 presents the surface roughness and contact angle attributes of board samples produced from both untreated and treated banana particles. The ANOVA test revealed a statistically significant distinction in surface properties between the experimental specimens of the untreated and treated sample groups. Subsequent application of the Duncan test identified three coherent and comparable groups within each dataset pertaining to surface roughness and contact angle.

Table 3. Surface roughness and contact angle properties of the boards produced from treated and untreated banana particles. (Alkali ön işlem görmüş ve görmemiş yongalardan elde edilen levhaların yüzey pürüzlülüğü ve temas açısı özellikleri).

Sample Type	Surface roughness (Ra) (‖)	Changes (%)	Contact Angle (°)	Changes (%)
Control	13.89 (1.46)[1] a[2]	-	67 (5.36) a	-
1% NaOH	10.56 (0.85) b	-23.9	54 (4.06) b	-19.4
3% NaOH	8.37 (0.66) c	-39.7	45 (3.74) c	-32.8
5% NaOH	7.22 (0.41) d	-48.1	39 (3.37) d	-41.8

[1]: Standard deviation, [2]: Groups defined by different letters in each column according to the Duncan test (surface roughness and contact angle $p<0.01$); N=10

Table 3 presents the average values of the three roughness parameters obtained from the sample surfaces. The average roughness parameter (Ra) exhibited a decrease with increasing solution ratio, ranging between 7.22 and 13.89. In comparison to the control group, the group treated with 1% NaOH displayed the smallest alteration, showing a 23.9% change, whereas the group treated with 5% NaOH demonstrated the most significant variation with a 48.1% shift. Research conducted by [41] established that the appropriate range of surface roughness for particleboard falls between 3.67 and 5.46 µm. Surface roughness is influenced by various factors, encompassing characteristics such as the annual ring structure, differentiation between hardwood and sapwood, as well as the distribution and cellular arrangement [42-44]. Moreover, the alkali concentration increase to a certain point is an effective method to increase the strength of banana fiber composites. However, increasing the concentration above certain points causes excessive "delignification" which causes weakening of fiber [45-47]. These fibers may increase adhesion and may also affect surface properties. Particles with enhanced adhesion potential could contribute to reduced roughness on the board surface.

Table 3 illustrates the contact angle values of the studied groups. It has been observed that as the NaOH concentration ratio increases, the contact angle decreases, with values ranging between 39 and 67. The highest hydrophobic sample group, exhibiting a contact angle of 67 was determined to be the control group, indicating a 41.8% decrease in hydrophobicity compared to the group treated with a 5% NaOH solution. Consistent with the findings regarding water absorption, an increase in NaOH solution ratio resulted in a decrease in the contact angle. The effect of alkali treatment on lignocellulosic material has been demonstrated by some studies. Enhanced deformation in the fibers makes the structure more hydrophilic. This situation can be explained by the gradual decrease of the contact angle on the surface [48-51].

4. CONCLUSIONS (SONUÇLAR)

In this study, banana waste materials (leaves and stem) made into particles were treated with 1%, 3% and 5% NaOH solutions. The alkali treatments effects on the physical and mechanical properties and surface properties of the particleboards produced were analyzed. The study was also conducted to highlight the significance and scale of banana plant waste. Elevating the concentration of NaOH application caused the boards to have more hydrophilic properties. This aspect warrants further investigation, particularly in the context of utilizing banana waste biomass. The findings indicate that only boards manufactured with 1% NaOH treated particles fulfilled the minimum requirements for mechanical properties specified for TS-EN 312, 2012. However, the mechanical properties of the particleboards show promising results in terms of achieving the desired values through the development of different methods. It was determined that the contact angle values decreased as the NaOH solution concentration increased. Despite that, It was observed that the surface roughness gradually decreased with increasing NaOH solution. By conducting various surface properties research, boards with more quality surface properties obtained from banana waste can be produced.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Abdullah BERAM*:** He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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