International Journal of Agriculture, Environment and Food Sciences

e-ISSN: 2618-5946 https://dergipark.org.tr/jaefs

DOI: https://doi.org/10.31015/2025.3.33 Int. J. Agric. Environ. Food Sci. 2025; 9 (3): 930-938

Investigating the Intrinsic Physical and Technological Properties of Naturally Grown Christ's Thorn (*Paliurus spina-christi* Mill. L.) in Türkiye: A Comprehensive Analysis

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Article History
Received: July 16, 2025
Accepted: September 18, 2025
Published Online: September 24, 2025

Article Info
Type: Research Article
Subject: Agricultural Machine Systems

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Available at
https://dergipark.org.tr/jaefs/issue/93545/1743714

DergiPark AKADEMIK

Abstract

The physico-mechanic properties of Christ's Thorn (*Paliurus spina-christi* Mill. L.) seeds are crucial for optimizing the design and efficiency of equipment used in handling, harvesting, processing, and storage. This study investigated various physico-mechanic and technological characteristics of Christ's Thorn seeds, including dimensional attributes, thousand seed mass, aritmetic and geometric mean diameter, sphericity, bulk an true densities, rupture strength, porosity, terminal velocity and projected areas. The findings indicated that the thousand-seed weight was between 19.13- 23.17 g, the geometric mean diameter was 3.28 mm, aritmetic mean diameter was 3.51 mm and the sphericity was determined to be 93.50%. Furthermore, the projected area was measured as varied from 13.85 to 15.53 mm^2, bulk density values ranged from 689.00 to 536.33 kg m^{-3} across different moisture levels while its true density varied between 1092 and 1004 kg m^{-3}. In addition to these, rupture strength decreased from from 23.16 to 13.32 N mm^{-2}, terminal velocity values were found between 2.97 and 3.40 m s^{-1}, porosity varied from 36.9% and 46.58% respectively. This study further explored the physical and technological attributes of Christ's Thorn, including length, width, thickness, sphericity, projected area, porosity, terminal velocity, and rupture strength, while also assessing the interrelationships among these parameters. These properties are essential in the development of agricultural machinery, as they directly influence key design aspects. The experimental measurements were conducted using methodologies, including a biological material testing device, image processing techniques, and a terminal velocity measurement instrument, ensuring precise and reliable data acquisition.

Keywords: Christ's Thorn (*Paliurus spina-christi Mill.* L.), image processing, moisture content, physico-mechanical properties

Cite this article as: Yalcin Dokumaci, K. (2025). Investigating the Intrinsic Physical and Technological Properties of Naturally Grown Christ's Thorn (*Paliurus spina-christi* Mill. L.) in Türkiye: A Comprehensive Analysis. International Journal of Agriculture, Environment and Food Sciences, 9 (3): 930-938. https://doi.org/10.31015/2025.3.33

INTRODUCTION

Paliurus spina-christi Mill. L. (Christ's Thorn), a resilient shrub native to the Mediterranean region, including Türkiye, has garnered interest for its potential applications in various fields, ranging from traditional medicine to ecological restoration (Bozkurt & Terzioğlu, 2017). Understanding the intrinsic physical and technological properties of *Paliurus spina-christi* is crucial for optimizing its utilization and exploring its economic potential in Türkiye, where it grows naturally in diverse habitats (Çalışkan et al., 2012). This necessitates a comprehensive analysis of its morphological characteristics, mechanical properties, chemical composition, and technological suitability for different applications (Celikel et al., 2008). Such research aligns with broader efforts to characterize and utilize native plant species for their beneficial properties, promoting both economic growth and environmental sustainability. The exploration of medicinal and aromatic plants is vital for economic benefit and cultural integration, emphasizing the need for skilled experts in substance isolation (Kılıç et al., 2017). Furthermore, some of these plant species are rare or endemic and their chemical composition and biological attributes are yet to be investigated (Perrino et al., 2021). The investigation of such plants can be used to develop new strategies for traditional and modern medicine (Docot et al., 2022).

Paliurus spina-christi Mill. L. is a leaf-shedding shrub or compact tree usually reaching a height of 3–6 meters. It features distinctive zigzagging branches equipped with paired spines and belongs to the Rhamnaceae family, commonly known as the buckthorn family. Its natural range spans, Southern Europe, North Africa, and Turkey in Mediterranean Basin, Israel, Jordan, Syria, and Iran in Middle East and Afghanistan and the Caucasus region in Central Asia as well (Danin, 2004).

In Turkey, Christi's thorn is commonly known by various local names depending on the region and dialect. Some of these names include "karaçalı, kara diken, çalı dikeni, sincan dikeni, çakal eriği, yabani erik, isadikeni, and geçit dikeni" (Deligöz et al., 2007). *Paliurus spina-christi* Mill. has been used in folk medicine across its native range for centuries. Leaf and fruit extracts contain flavonoids (e.g., rutin) and triterpenoid saponins, which exhibit anti-inflammatory effects. Traditional remedies use decoctions to treat joint pain and rheumatic conditions (Altundag and Ozturk, 2011). Studies suggest that fruit extracts may help regulate blood glucose levels by inhibiting carbohydrate-digesting enzymes (Orhan et al., 2012). In Turkish folk medicine, fruit infusions are consumed to support kidney function and treat urinary tract infections (Yesilada et al., 1999). High phenolic content in leaves and fruits scavenges free radicals, potentially reducing oxidative stress.

Additionally, Dökülgen and Temel (2015) conducted a study on the seasonal variation of nutrient content in the leaves and shoots of the Christ's Thorn plant (*Paliurus spina-christi* Mill.) for use as animal feed. Their findings indicated that leaf samples consistently produced higher-quality feed compared to leaf + shoot samples across all growth stages. Furthermore, the study demonstrated that Christ's Thorn could meet the daily nutrient requirements of small ruminants as recommended by NRC (2007) for both feed types (leaves and leaves + shoots) and across different seasons (except autumn) without the need for additional supplementation. A study conducted in Isparta, Turkey, determined that the average weight of 1,000 seeds of Christ's Thorn (*Paliurus spina-christi* Mill.) was 21.2 grams. The same study reported that 6% of capsules contained 4 seeds, 31% contained 2 seeds, and 63% contained 3 seeds, resulting in an average of 2.72 seeds per capsule (Deligöz et al., 2007).

In 2005, seeds collected from the Hamamlı region of Ardanuç, Artvin, were analyzed, and the 1,000-seed weight was found to be 20.18 grams (Tilki and Kebeşoğlu, 2009). Due to the hard seed coat of christ's thorn (*Paliurus spina-christi* Mill. L.), germination rates are generally low. Tilki and Kebeşoğlu (2009) investigated different treatments to overcome seed dormancy, including sulfuric acid treatment, cold stratification, and their combination. Their findings indicated that combining sulfuric acid treatment with stratification significantly improved germination rates and speed. Kemertelidze et al. (1999) highlights several potential health benefits of *Paliurus spina-christi* Mill. L. for human health, particularly in the areas of liver protection, bile secretion, and antioxidant effects. Brantner et al. (1996) investigated the antibacterial properties of *Paliurus spina-christi* Mill. and found that it exhibits significant antibacterial activity against Gram-positive bacteria. Among the tested Christ's thorn plant parts, the root extract showed the strongest antibacterial effect. The study highlighted that flavonoids play a key role in the antimicrobial activity, suggesting the potential use of *Paliurus spina-christi* in natural antimicrobial treatments. However, limited or no antibacterial effect was observed against Gram-negative bacteria, including Escherichia coli. The cultivation of Christ's thorn on large-scale agricultural lands would provide numerous benefits both for human health and as animal feed. Previous research has highlighted not only the nutritional and technological potential of Paliurus spina-christi but also its pharmacological value. For instance, Takım and Işık (2020) demonstrated that fruit extracts of P. spina-christi exert significant antioxidant effects and modulate oxidative stress in diabetic rats. Similarly, Takım (2021) provided comprehensive LC-MS/MS evidence showing that decoction extracts of the fruit are rich in bioactive phenolics such as rutin, catechin, hesperidin, quinic acid, and malic acid, and confirmed their strong antidiabetic activity in streptozotocin-induced diabetic models.

Recent studies have highlighted the importance of characterizing the physical properties of seeds from local plant populations. For example, Hacıseferoğulları and Temel (2024) investigated the dimensional, physical, and germination properties of Ereğli and Kırıkhan local black carrot (*Daucus carota* L.) populations, emphasizing their relevance for seed certification, storage, and mechanization practices. Such findings support the necessity of comprehensive evaluations for other species, including Christ's thorn, to optimize post-harvest handling and processing.

However, no studies have been conducted on identifying the physico- technological properties necessary for designing and developing agricultural mechanization equipment used across the entire cultivation process, from sowing to harvesting. Similar efforts on other horticultural products, such as cherry tomatoes, have shown that storage time and compression position significantly affect deformation, rupture force, and Poisson ratio (Arkain & Saraçoğlu, 2023). Comparable moisture-dependent trends in seed physico-mechanical behavior have also been reported for other Mediterranean species. For example, Ecballium elaterium seeds exhibited decreasing bulk and true densities with increasing moisture, alongside rising projected area and terminal velocity, underscoring the generality of these design-relevant patterns (Kayahan, 2024). This study seeks to conduct a detailed examination of the inherent physical and technological properties of naturally grown Christ's thorn seeds to aid in equipment design and optimization for large-scale production.

MATERIALS AND METHODS

Christ's thorn (*Paliurus spina-christi* Mill.) seeds used in this study were collected on 28 July 2022 from Çandır village, located in the Köyceğiz district of Muğla province, Türkiye. Seeds were separated from three-chambered capsules, cleaned from external contaminants (dust, branches, leaves, immature or damaged fruits), and dried in an oven to determine their initial moisture content. The initial moisture content was measured according to the USDA (1970) standard method and found to be 7.69% (d.b.).

Following moisture determination, the seeds were humidified by adding a predetermined amount of distilled water, thoroughly mixed, and sealed in polyethylene bags to reach the desired moisture levels. The samples were then stored at 278

K for seven days to ensure uniform moisture distribution (Deshpande et al., 1993; Çarman, 1996; Konak et al., 2002). Experimental measurements were conducted at six different moisture levels: 7.69%, 10%, 12%, 14%, 16%, and 18% (d.b.), with each test performed in triplicate.

For dimensional analysis, ten groups of 100 randomly selected seeds were prepared. From each group, 30 seeds were measured for their length (L), width (W), and thickness (T) using an electronic micrometer with 0.01 mm precision. Based on these values, the geometric mean diameter (Dg) and sphericity (φ) were calculated according to Mohsenin (1986):

$$\mathrm{Dg} = (\mathrm{L.W.T})^{1/3} \quad (1)$$

$$\mathrm{Da} = \frac{(\mathrm{L.W.T})}{3} \quad (2)$$

$$\phi = \frac{\mathrm{Dg}}{\mathrm{L}} \times 100 \quad (3)$$

Projected seed areas were determined using a digital imaging method. A 16 MP camera was mounted 30 cm above the seeds placed on a light-colored background alongside a reference plate. Images were processed using FIJI software on a computer (2.4 GHz processor) to calculate projected areas.

Bulk density was determined with a hectoliter weight tester (kg hL^{-1}) following Deshpande et al. (1993). True density was measured by the liquid displacement method, using toluene instead of water to minimize absorption (Sitkei, 1976; Mohsenin, 1970; Haciseferoğulları et al., 2005). Porosity (ε) was calculated from true and bulk density values as:

Porosity (ε) was calculated using the following equation, as described by Mohsenin (1970) and Thompson & Isaacs (1967). Where ρ_t represents the true density and ρ_b denotes the bulk density.

$$\varepsilon = \left(\frac{\rho_t - \rho_b}{\rho_t}\right) \times 100 \quad (4)$$

The terminal velocity (Vt) of seeds was measured in an air column by releasing seeds individually into an upward air stream. The velocity at which the seed remained suspended was recorded using an anemometer with 0.1 m s^{-1} precision (Hauhouot-O'Hara et al., 2000; Joshi et al., 1993). Measurements were performed on 25 randomly selected seeds (Fig. 1).

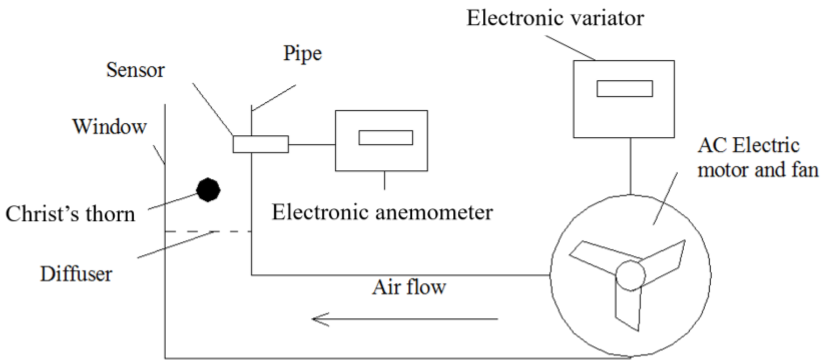

Figure 1. Measurement unit for terminal velocity

The rupture strength of seeds was determined using a biological material testing device developed by Aydın and Öğüt (1992). A 2.2 mm diameter probe attached to a force dynamometer (0.01 N precision) was pressed into the seed at a constant speed of 50 mm min^{-1} until rupture occurred. Force values were recorded through a data acquisition system (Fig. 2).

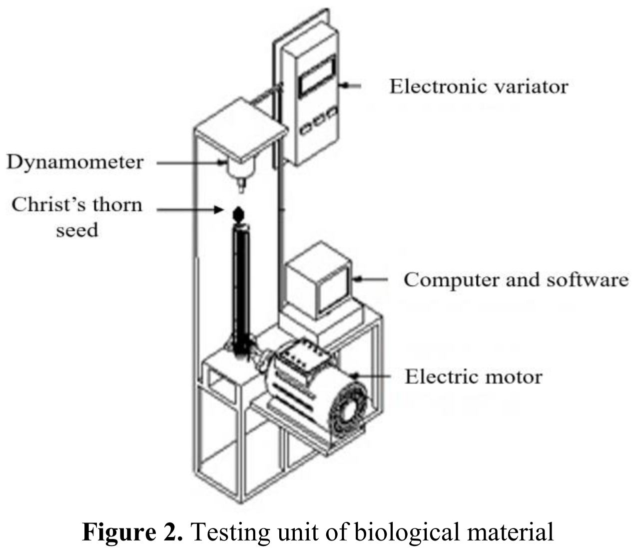

Figure 2. Testing unit of biological material

All experimental data were statistically evaluated, and graphical representations were generated using the Matplotlib library in Python.

RESULTS AND DISCUSSION

The results of this study reveal key physico-technological properties of *Paliurus spina-christi Mill. L.* seeds that are critical for designing agricultural machinery and optimizing post-harvest processing systems.

Results for Physical properties of Christ's Thorn

The measured thousand-seed weight ranged from 19.13 g at 7.69% moisture content to 23.17 g at 18% moisture content, indicating a positive linear relationship between moisture content and seed mass. This observation aligns with findings reported for almond kernels (Aydın, 2003) and neem nuts (Visvanathan et al., 1996), where increased moisture content was associated with increased kernel weight due to water absorption and cell turgidity.

The dimensional properties of Christ's Thorn at an initial moisture content of 7.69% are presented in Table 1. The weight of a thousand Christ's Thorn seeds (m_{1000}) showed a linear rise, ranging from 19.13 g at 7.69% to moisture content (d.b.) to 23.17 g at 18% (d.b.). Some other dimensional properties were measured 4.58- 4.89 mm for length, 4.03-4.18 mm for width, 1.92-2.03 mm for thickness and sphericity was found between 93.50-93.55% respectively. Additionally, the geometric mean diameter (D_g) and arithmetic mean diameter (D_a) of Christ's Thorn varied from 3.28 to 3.46 mm and 3.51 to 3.70 mm, respectively.

The relationships between moisture content and seed properties observed in Christ's thorn are consistent with other reports on small-seeded crops. Hacıseferoğulları and Temel (2024) demonstrated similar correlations for black carrot seeds, where parameters such as geometric mean diameter, sphericity, bulk density, and terminal velocity were quantified alongside germination behavior. These parallels reinforce the universality of seed physico-mechanical responses across species and highlight their engineering significance.

Table 1. The average values and standard errors of Christ's thorn dimensions at a moisture content of 7.69% db.

Properties	Mean±SD
m_{1000} (g)	19.13±0.30
Length (L) (mm)	4.58±0.21
Width (W) (mm)	4.03±0.28
Thickness (T) (mm)	1.92±0.10
D_g (mm)	3.28±0.11
D_a (mm)	3.51±0.13
Sphericity (ϕ) (%)	93.5±0.91

The relationship among the average seed dimensions at a moisture content of 7.69% dry basis can be expressed using the following general equation:

$$L=1.136 \times W=2.385 \times T=1.396 \times D_g=1.305 \times D_a=0.049 \times \phi \quad (4)$$

The statistical analysis results of the dimensional ratios are presented in Table 2. The analysis revealed distinct relationships between seed length and the other morphological parameters.The mean length-to-width (L/W) ratio was calculated as 1.14, indicating that the seeds are, on average, slightly longer than their width. However, the correlation between length and the L/W ratio was not statistically significant ($r = 0.496$; $p > 0.05$), suggesting that width does not proportionally increase with seed length. In contrast, the length-to-thickness (L/T) ratio exhibited a mean value of 2.39, with a strong and statistically significant positive correlation with length ($r = 0.698$; $p < 0.05$). This finding demonstrates that longer seeds tend to be relatively thinner, highlighting a consistent proportionality between these two traits. Similarly, the length-to-geometric mean diameter (L/GMD) and length-to-arithmetic mean diameter (L/AMD) ratios, with mean values of 1.40 and 1.30, respectively, were positively and significantly correlated with seed length ($r = 0.687$ and $r = 0.637$; $p < 0.05$). These results emphasize that both geometric and arithmetic mean diameters scale proportionally with seed length. Among all ratios, the length-to-sphericity (L/ ϕ) ratio demonstrated the highest correlation with seed length ($r = 0.771$; $p < 0.01$), despite its relatively small mean value (0.05). This indicates that longer seeds tend to exhibit greater sphericity, suggesting a close geometric relationship between seed elongation and overall shape.

Overall, these findings highlight that while seed width shows limited dependence on length, thickness, mean diameters, and sphericity are strongly and positively influenced by seed length. This implies that length is a critical factor in determining the geometric uniformity and shape characteristics of the seeds.

Table 2. Correlation coefficients between seed length and dimensional ratios (L/W, L/T, L/GMD, L/AMD, L/ ϕ) of Christ's thorn seeds at 7.69% (d.b.) moisture content.

Particulars	Mean	Degrees of freedom	Coefficient of correletion
L/W	1.140	28	0.496
L/T	2.392	28	0.698
L/ D_g	1.396	28	0.687
L/ D_a	1.305	28	0.637
L/ ϕ	0.049	28	0.771

**Significant at $p < 0.01$

Results for Mechanical properties of Christ's Thorn

Bulk and true density

The bulk and true density of Christ's Thorn exhibited changes in response to varying moisture content. In Figure 3, the bulk density of Christ's Thorn ranged from 689 to 536.33 kg m^{-3} across different moisture levels while its true density varied between 1092 and 1004 kg m^{-3}. The effect of moisture content on density of christ's thorn showed that bulk and true density decreased with increasing moisture content. A negative linear correlation between density and moisture content was observed, attributed to the limited volumetric expansion of the seed as moisture increases while its mass continues to rise. This inverse relationship, also documented by Pliestic et al. (2006) for filberts and Baryeh (2001) for Bambara groundnuts, can be attributed to the expansion of intercellular spaces and increased seed volume without proportional mass gain at higher moisture levels. These findings are crucial for storage design since lower bulk densities at higher moisture contents could increase void spaces, leading to reduced storage efficiency. For neem nuts, Visvanathan et al. (1996) found out a negative linear correlation between bulk and true density, Baryeh (2001) was also noted for Bambara groundnuts, Aydin (2002) for hazelnuts, and Pliestic et al. (2006) for filberts as well. Unal et al. (2008) reported that the true density of mung bean grains was measured at different moisture levels, showing a linear increase and ranging from 1230.0 to 1456.7 kg m^{-3}. The present results on Christ's Thorn are in line with those reported for pecan seeds (*Carya illinoinensis*) by Çelik (2024), where bulk and true densities decreased with increasing moisture, while projected area and terminal velocity showed a positive trend. The decrease in rupture strength with higher moisture levels, observed in both species, highlights the universal importance of considering seed moisture content in the design of harvesting, threshing, and conveying systems.

Porosity

The porosity of Christ's Thorn varied between 36.9% and 46.58% across different moisture levels. It was found that the porosity of Christ's Thorn did not show a regular change with the increase in moisture level (Fig. 3).

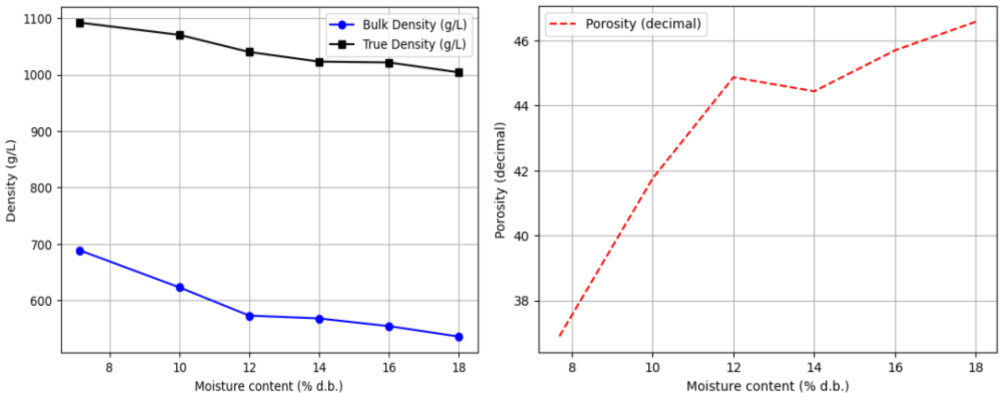

Figure 3. Variation of bulk density, true density, and porosity of *Paliurus spina-christi* Mill. L. seeds at different moisture contents (7.69–18% d.b.)

Projected area

The projected area of Christ's Thorn at different moisture levels varied from 13.85 to 15.53 mm^2 (Fig. 4). An increase in moisture content causes an increase in projected area 12%. Moreover, the kernel's projected area increased by approximately 42.35%, while its moisture content rose from 2.77% to 24.97% on a dry basis (Aydin, 2003). A similar pattern has been observed in various other seed types in Mohsenin, 1970; Sitkei, 1986; Dehspande et al., 1993 as well.

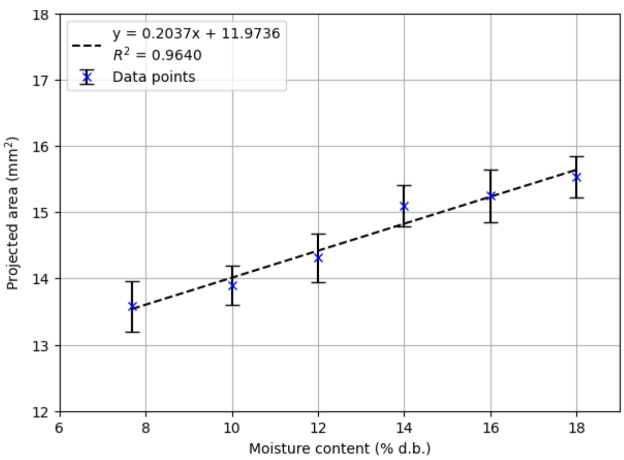

Figure 4. Effect of moisture content on the projected area of christ's thorn

Terminal velocity

The terminal velocity of Christ's Thorn varied between 2.97 and 3.40 m s⁻¹ at different moisture levels (Fig. 5). A linear increase in terminal velocity was observed with rising moisture content. A 5% increase in moisture content resulted in an average 6% increase in terminal velocity. Similar findings have been reported by other researchers (Kural and Çarman, 1997; Aydin, 2003; Haciseferogullari et al., 2005). Higher terminal velocities at elevated moisture levels imply that separation systems utilizing air streams must be recalibrated to maintain efficiency.

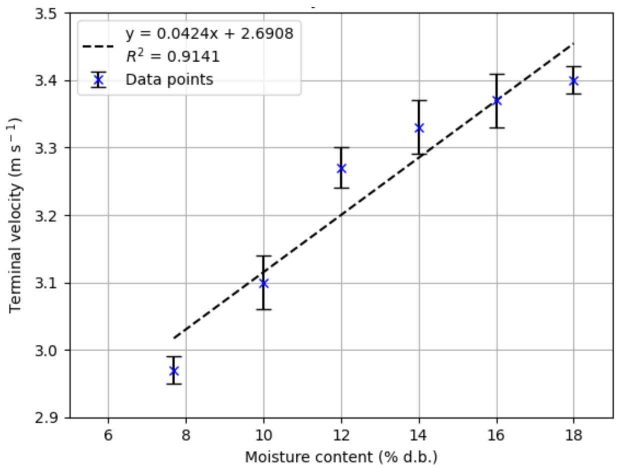

Figure 5. Variation of terminal velocity of christ's thorn with moisture content

Rupture strength

Rupture strength values exhibit a decreasing trend as moisture levels increase, ranging from 23.16 to 13.32 N mm^{-2}, as shown in Figure 6. The rupture strength of Christ's Thorn shows a linear relationship with moisture content variation. The lower rupture forces at higher moisture content may be attributed to the kernel becoming significantly softer as moisture levels increase. This inverse relationship is critical for machinery design, as lower rupture strength at higher moisture levels necessitates careful handling to minimize mechanical damage during threshing and conveying operations. The decreasing rupture strength of Christ's Thorn seeds with increasing moisture content is in line with the trends observed in cherry tomatoes by Arkain and Saraçoğlu (2023), who showed that prolonged storage led to increased deformation and reduced mechanical resistance. This comparison underscores the universal role of moisture and storage conditions in shaping the mechanical behavior of biological materials. Ekinci et al. (2010) reported that the rupture force of carob pod seeds decreased with increasing moisture content, similar to Christ's Thorn, Aydın (2003) reported similar findings for almond nuts and kernels as well.

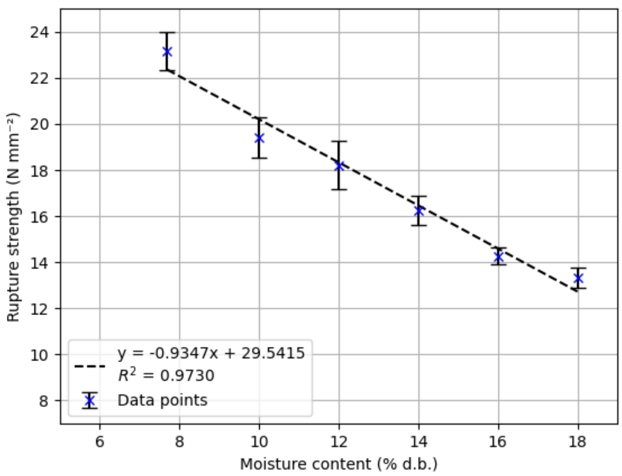

Figure 6. Variation of rupture strength of christ's thorn with moisture content

Overall, the physical and mechanical data suggest that moisture content significantly affects seed properties, which must be considered when designing equipment for cleaning, grading, transporting, and storing *Paliurus spina-christi* Mill. L. seeds. Similar to the findings of Hacıseferoğulları and Temel (2024) on black carrot seeds, the determination of dimensional properties, density, terminal velocity, and friction coefficients provides essential input parameters for the design of storage, cleaning, grading, and pneumatic precision planting machinery.

CONCLUSION

This study investigated the physico- technological properties of the wild form of Christ's Thorn (*Paliurus spina-christi* Mill. L.) seeds. At an initial moisture content of 7.69% (d.b.), the physical dimensions, including length, width, and thickness, were measured as 4.58 mm, 4.03 mm, and 1.92 mm, respectively. Based on these measurements, the sphericity was calculated as 93.50%. Additionally, the geometric and arithmetic mean diameters were determined to be 3.28 mm and 3.51 mm, respectively. Understanding these physical and technological properties is critical for enhancing the design, efficiency, and performance of agricultural machinery utilized in plantation, harvesting, transportation, storage, and processing operations.

The results indicated that as moisture content increased, both bulk and true densities exhibited a decreasing trend, while porosity and projected area increased. Furthermore, projected area and terminal velocity showed a positive correlation with increasing moisture levels, whereas rupture strength declined. These findings provide valuable insights for optimizing threshing efficiency, improving pneumatic conveying and transportation processes, enhancing storage strategies, and facilitating the development of specialized machinery for processing *Paliurus spina-christi* Mill. seeds.

The projected area and terminal velocity of Christ's Thorn seeds exhibited an increasing trend with rising moisture content, whereas its rupture strength declined as moisture levels increased. Conversely, an increasing moisture content was observed to result in a decreasing trend in both bulk and true density values.

The identified properties serve as fundamental parameters for the design and optimization of threshing, cleaning, and separation equipment, as well as storage structures and transportation systems for Christ's Thorn, a species with significant potential as a forage crop and alternative cultivated plant. These characteristics are essential for determining sizing specifications, material selection, and operational parameters in the development of pneumatic conveying systems and other transportation mechanisms. For instance, terminal velocity is a crucial factor in designing the fan system of a harvester.

In summary, this study highlights and discusses the critical physico-technological characteristics of *Paliurus spina-christi Mill*. L. seeds and their implications for agricultural engineering applications. Key finding of this study:

- Increasing moisture content leads to higher thousand-seed weight and projected area, while reducing bulk and true densities.
- Terminal velocity increases with moisture, requiring adjustments in pneumatic conveying systems.
- Rupture strength decreases as moisture rises, highlighting the need for gentle handling mechanisms to reduce seed breakage.

These results offer critical insights for the design and optimization of agricultural machinery and post-harvest systems, such as threshers, pneumatic conveyors, and storage facilities, tailored specifically for *Paliurus spina-christi* Mill. L.. Future studies should investigate the interaction of these properties with mechanical components under field conditions to validate design parameters. Additionally, integrating these findings with computational modeling could enable predictive simulations for large-scale processing operations.

Compliance with Ethical Standards

Peer Review

This article has been peer-reviewed by independent experts in the field using a double-blind review process.

Conflict of Interest

The author declares that there is no conflict of interest.

Author Contribution

The author solely conceived, designed, and conducted the study, analyzed the data, and wrote the manuscript.

Ethics Committee Approval

Ethical approval was not required for this study.

Consent to Participate / Publish

Not applicable.

Funding

The author declares that this study received no financial support.

Data Availability

Not applicable.

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