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# Determination of Some Physical Properties of Wild Stone Pine (*Pinus pinea* L.) Kernel and Pits Grown in Turkey

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**ABSRACT**

In this research, some of physical properties at various moisture content were determined for *Pinus pinea* L. fruits (stone pine) collected from the region of Mut (İçel), Turkey. The physical properties of stone pine kernel and pits were determined as a function of moisture content in the range of 7.25-20.52% and 8.82-28.84 % dry basis (d.b.) for pit and kernel respectively. The correlation coefficient between length and mass of stone pine pit and kernel were found significant at 7.25% and 8.82% moisture content (d.b.) for pit and kernel respectively. As the moisture content increased, the sphericity, thousand grain mass, bulk density, true density, terminal velocity, and projected area increased for stone pine pit and kernel. The coefficient of static friction of stone pine pit and kernel increased against the surface of two structural materials, namely, a galvanised steel sheet (0.343-0.489) and plywood sheet (0.5-0.521) for stone pine pit, and a galvanized steel sheet (0.383-0.435) and plywood sheet (0.442-0.471) for stone pine kernel as the moisture content from 7.25 to 20.52% and 8.82 to 28.84% (d.b.), respectively. Both the rupture strength value of stone pine pit and the hardness of stone pine kernel decreased as the moisture content increased.

## 1. Noienclature

| | | |
|---|---|---|
| $p$ | : | Stone pine pit |
| $k$ | : | Stone pine kernel |
| $L_p$ | : | Length of stone pine pit [mm] |
| $L_k$ | : | Length of stone pine kernel [mm] |
| $W_p$ | : | Width of stone pine pit [mm] |
| $W_k$ | : | Width of stone pine kernel [mm] |
| $T_p$ | : | Thickness of stone pine pit [mm] |
| $T_k$ | : | Thickness of stone pine kernel [mm] |
| $M_p$ | : | Mass of stone pine pit [g] |
| $M_k$ | : | Mass of stone pine kernel (g] |
| $\Phi_p$ | : | Spericity of stone pine pit [-] |
| $\Phi_k$ | : | Spericity of stone pine kernel [-] |
| $m_p$ | : | Moisture content of stone pine pit [%] d.b. |
| $m_k$ | : | Moisture content of stone pine kernel [%] d.b. |
| $m_{1000p}$ | : | Thousand grain mass of stone pine pit (g] |
| $m_{1000k}$ | : | Thousand grain mass of stone pine kernel [g] |
| $\rho b_p$ | : | Bulk density of stone pine pit [kg m$^{-3}$] |
| $\rho b_k$ | : | Bulk density of stone pine kernel [kg m$^{-3}$] |
| $\rho t_p$ | : | True density of stone pine pit [kg m$^{-3}$] |
| $\rho t_k$ | : | True density of stone pine kernel [kg m$^{-3}$] |
| $v_p$ | : | Terminal velocity of stone pine pit [m s$^{-1}$] |
| $v_k$ | : | Terminal velocity of stone pine kernel [m s$^{-1}$] |
| $Pa_p$ | : | Projected area of stone pine pit [cm$^2$] |
| $Pa_k$ | : | Projected area of stone pine kernel (cm$^2$] |
| $\varepsilon_p$ | : | Porosity of stone pine pit [%] |
| $\varepsilon_k$ | : | Porosity of stone pine kernel [%] |
| $\mu_p$ | : | Coefficient of static friction of stone pine pit |
| $\mu_k$ | : | Coefficient of static friction of stone pine kernel |
| $F$ | : | Rupture force [N] |
| $H$ | : | Hardness [N] |

## 2. Introduction

Stone pine (*Pinus pinea*) from family Pinaceae is a pine species, which has shown distribution in the Aegean and Mediterranean coasts, Portugal, Spain, Italy, Crete and Turkey. Particularly in the West Anatolia, pine forests grow around the Bergama district, Aydın and Muğla provinces. They spread as local in the Manavgat district coasts of Antalya province, Gemlik district gulf sides, Maras province and Coruh canyon.

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The stone pine forests of Turkey cover 54 000 ha, and total cone production of the stone pine was approximately 3500 tons in 2006 according to the Forestry Statistics of Turkish General Directorate of Forestry (Büyüksarı et al. 2010).

Stone pine is used in the food industry. After the pine is broken and as soon as they are collected, they are eaten without the need for any treatment. It has a whitish colour and a special aroma. It contains excess protein and minerals. Also, it has an important place in medicine. It is used in the treatment of atherosclerosis, hypertension, duodenum, the stomach and cirrhosis. It is also used in cakes and other foods. The oil obtained from the pines has an important position in confectionery, vegetable dishes, margarine production and the cosmetic industry.

The physical, mechanical and aerodynamic properties of agricultural products are the most important parameters for the design and development of handling, sorting, processing, drying, packaging, transporting, storage systems, etc.

Shape, size, volume, surface area, density, porosity, colour and appearance are some of the physical characteristics that are significant in many of the problems associated with the design of a specific machine, or the analysis of the behaviour of the product in handling the material. Gravimetric properties are important in the design of equipment related to aeration, drying, storage and transport. Bulk density, true density and porosity can be useful in sizing grain, hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and the drying process. Bulk density determines the capacity of the storage and transport system, while true density is useful for separation equipment. Porosity of the mass of seeds determines the resistance to air flow during aeration and drying of seeds. It allows gases, such as air, and liquids to flow through a mass of particles in aeration, drying, heating, cooling and distillation operations. Aerodynamic properties such as terminal velocity are useful for air conveying pneumatic separation of materials in such a way that when the air velocity is greater than the terminal velocity, it lifts the particles. The air velocity at which the seed remains in suspension is considered terminal velocity (Mohsenin 1986).

The static coefficient of friction is necessary for designing a conveying machine and hoppers used in planter machines. It is used to determine the angle at which chutes must be positioned in order to achieve a consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi Varnamkhasti et al. 2007).

Ozguven and Vursavus (2005) studied the physical, mechanical and aerodynamic properties of stone pine nuts at constant moisture content of 5.48% (d.b.). Ozcan et al. (2009) studied on physico-chemical properties of Turkish wild stone pine kernel and pits from Balya (Balıkesir), Turkey. Gharibzahedi et al. (2010) studied some engineering properties of pine nuts as a function of moisture content in the range of 6.3% to 20.1% (d.b.). Cárcel et al. (2012) studied moisture dependence on mechanical properties of pine nuts from Pinus pinea L. However, there is not enough information or study on chemical, physical, mechanical and aerodynamic properties of wild stone pine (*Pinus pinea* L.) pits and kernel grown in different regions of Turkey.

The objective of this study was to determine some physical properties of stone pine pit and kernel at different moisture contents such as dimensions, mass, spehricity, thousand grain mass, bulk density, true density, terminal velocity, projected area, porosity, static friction coefficient on various surfaces and hardness.

## 3. Material and Methods

Pine fruits were obtained from Mut (İçel) province in 2011. Foreign materials, leaves, immature and damaged kernels were removed. The remaining kernels were packed in a sealed glass jar and kept in cold storage (+4 $^{o}$C) for 10 days to enable the moisture to distribute uniformly throughout the product.

Stone pine pits and kernels were assessed at 7.25 – 20.52 % and 8.82 – 28.84 % moisture content (d.b.) respectively, because the processing with these products is usually carried out between these moisture content values.

The length, width, thickness and mass of stone pine pits and kernels were measured in randomly selected 100 stone pine pits and stone pine kernels at 7.25–20.52% and 8.82 – 28.84% moisture content (d.b.) respectively. A micrometer (0.001 mm accuracy) was used to measure the dimensions (length "*L*", width "*W*" and thickness "*T*") of the samples. The mass of grains and 1000 grain mass were measured by an electronic balance to an accuracy of 0.001 g. To evaluate 1000 grain mass, 100 randomly selected grains from the bulk were averaged.

Geometric mean diameter ($D_g$) and sphericity ($\Phi$) values were calculated using the following equations 1 and 2 (Mohsenin 1986; Jain and Bal 1997):

$$D_g = \left(LWT\right)^{0.033} \quad (1)$$

$$\Phi = \left(LWT\right)^{0.033} / L \quad (2)$$

The liquid (toluene $C_7H_8$) displacement method was used to determine the true density of stone pine pit ($\rho_p$) and kernel ($\rho_k$) as a function of moisture content (Mohsenin 1986; Singh and Goswami 1996). The bulk density ($\rho_b$) was determined with a weight per hectolitre tester, which was calibrated in kg per hectolitre (Desphande et al. 1993; Suthar and Das 1996; Jain and Bal 1997).

The porosity ($\varepsilon$) was determined by equation 3 given by Mohsenin (1986). $\rho_b$ is bulk density and $\rho_t$ is true density in porosity equation.

$$\varepsilon = 1 - \rho_b / \rho_t \quad (3)$$

The terminal velocities of stone pine and kernel at different moisture content were measured using an air column (Fig. 1). For each test, a sample was dropped into the air stream from the top of the air column, up from which air was blown to suspend the material in the air stream. The air velocity near the location of the grain suspension was measured by electronic anemometer having a least count of 0.1 m $s^{-1}$ (Joshi et al. 1993; Hauhout-O'hara et al. 2000).

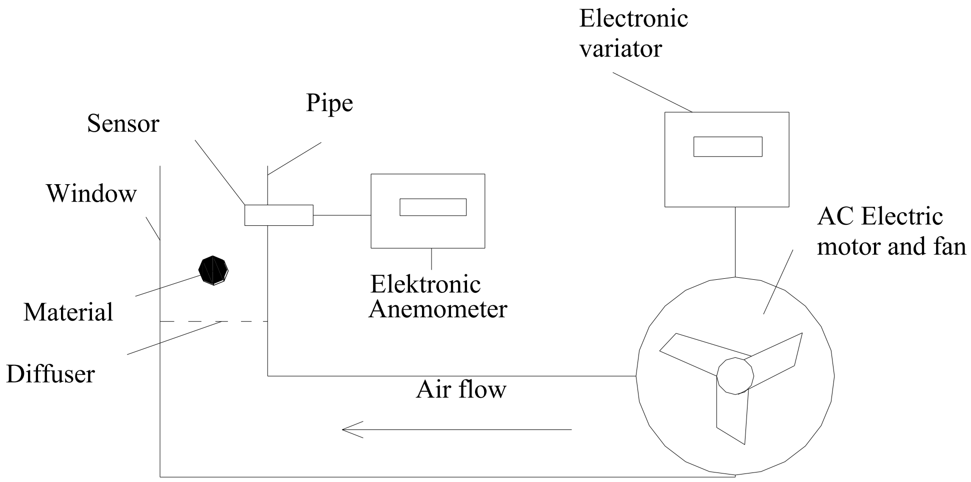



Figure 1
Unit for Measuring Terminal Velocity

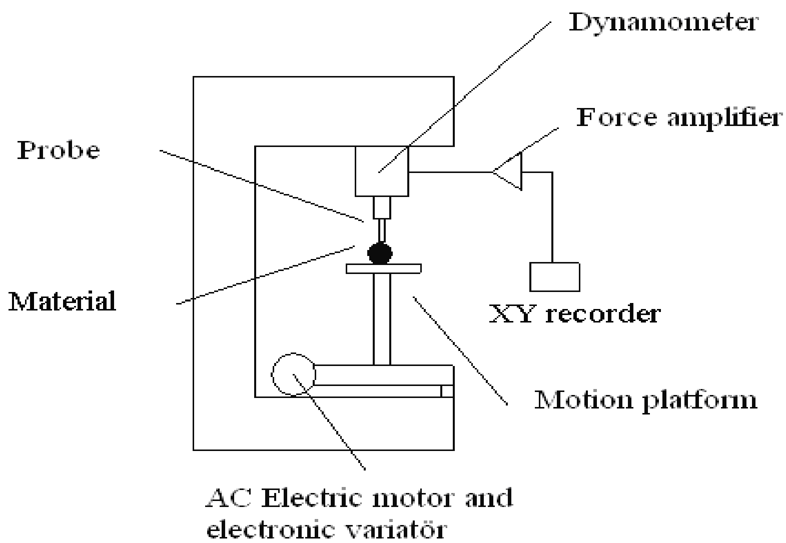



Figure 2
Biological Material Test Unit (B.M.T.U.)

For determination of the projected area a digital camera (Kodak DC 240) and Sigma Scan Pro 5 image processing software were utilized (Ayata et al. 1997; Trooien and Heerman 1992).

The coefficient of static friction was measured by using galvanised steel sheet and plywood sheet surfaces. For this measurement one end of the friction surface was attached to an worm gear mechanism. The grain was placed on the surface and it was gradually raised by the mechanism. Vertical and horizontal height values were read from the ruler when the grain started sliding over the surface; then using the tangent value of that angle, the coefficient of static friction was calculated. The similar measurement method has been put in practice by Baryeh (2001), Dutta et al. (1988), Suthar and Das (1996).

The rupture strength values of pit and kernel were measured by forces applied through three axes (length–$F_x$, width–$F_y$ and thickness–$F_z$). The hardness values of kernel were measured by forces applied through one axis (width–$F_y$). To determine the rupture strength of kernels, a biological material test device was used (Fig. 2). The device, developed by Aydın and Ogut (1991), has three main components: stable up and motion bottom of platform, a driving unit (AC electric motor and electronic variator) and the data acquisition (dynamometer, amplifier and XY recorder) system. The rupture force of the kernel was measured by the data acquisition system. The stone pine pit and kernel were placed on the moving bottom platform and pressed with stationary platform. A probe used with a 2 mm diameter in the experiment for the hardness of kernels was connected to dynamometer. The experiment was conducted at a loading velocity of 50 mm min$^{-1}$.

## 3. Results and Discussion

### *3.1. Stone Pine Pit Kernel Dimensions and Grain Distribution*

Mean values of length, width, thickness, mass, geometric mean diameter and sphericity for 100 samples of stone pine pits and their kernels are given in Table 1. Generally, the length, width, thickness, mass and geometric mean diameter values of stone pine pits and kernels increased depending on increasing moisture content. These increments can probably be explained by some tiny air voids on the grains. Similar results for soybeans and bambara groundnuts were reported by Deshpande et al. (1993) and Baryeh (2001) respectively.

Table 1

Dimensional properties of stone pine pit and kernel*

| | Stone pine pit | | | |
|---|---|---|---|---|
| Moisture | %7.25 | %9.96 | %16.34 | %20.52 |
| Length (mm) | 17.45±0.116 | 17.48±0.111 | 17.51±0.118 | 17.42±0.122 |
| Width (mm) | 8.02±0.065 | 8.06±0.060 | 8.12±0.056 | 8.19±0.072 |
| Thickness (mm) | 6.70±0.055 | 6.72±0.052 | 6.85±0.063 | 6.91±0.057 |
| Mass (g) | 0.529±0.010 | 0.568±0.009 | 0.587±0.008 | 0.605±0.005 |
| GMD**(mm) | 9.77±0.052 | 9.81±0.045 | 9.88±0.049 | 9.93±0.0057 |
| Sphericity (-) | 56.13±0.307 | 56.63±0.295 | 56.98±0.315 | 57.17±0.332 |
| | Stone pine kernel | | | |
| Moisture | %8.82 | %12.24 | %21.63 | %28.84 |
| Length (mm) | 13.28±0.76 | 13.45±0.74 | 13.47±0.76 | 14.78±0.99 |
| Width (mm) | 5.04±0.051 | 5.12±0.046 | 5.76±0.050 | 5.82±0.57 |
| Thickness (mm) | 4.01±0.040 | 4.09±0.042 | 4.44±0.038 | 4.57±0.041 |
| Mass (g) | 0.157±0.003 | 0.162±0.007 | 0.212±0.009 | 0.247±0.004 |
| GMD**(mm) | 6.44±0.039 | 6.51±0.035 | 6.89±0.039 | 7.31±0.045 |
| Sphericity (-) | 48.55±0.300 | 48.77±0.329 | 49.05±0.315 | 49.56±0.309 |

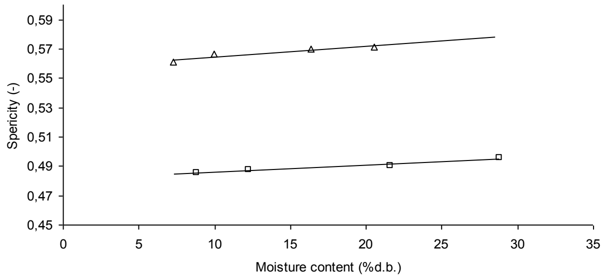
* All data represent of hundered pit and kernel values

** Geometric mean diameter

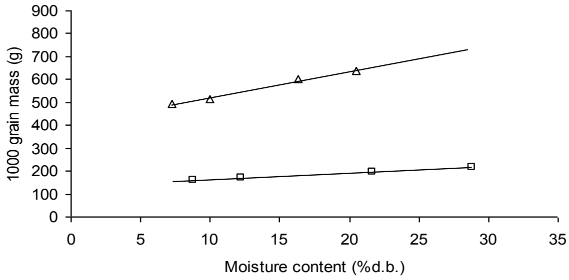
According to the measurements of 100 samples, 82% of stone pine pits have a length ranging from 16 to 19 mm, 10% of stone pine pits have a length less than 16 mm and 8% of stone pine pits have a length more than 19 mm at a moisture content of 7.25%. 80 % stone pine kernels have a length ranging from 12 to 14 mm, 5% of them have a length less than 12 mm and 15% of them have a length more than 14 mm at a moisture content of 8.82%. The relationships between length, width, thickness and mass of stone pine pits and their kernels are given by the following equations 4 and 5.

$$L_p = 2.18W_p = 2.60T_p = 33.00M_p \text{ (stone pine pit)} \quad (4)$$

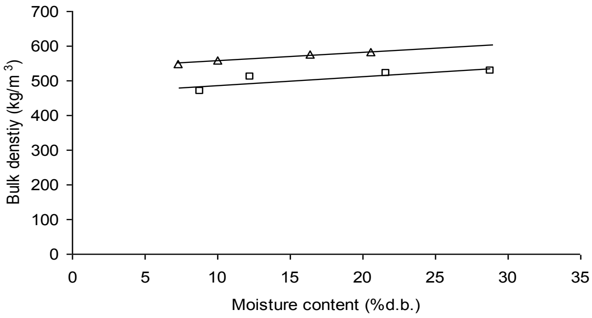
$$L_k = 2.64W_k = 3.31T_k = 84.59M_k \text{ (stone pine kernel)} \quad (5)$$



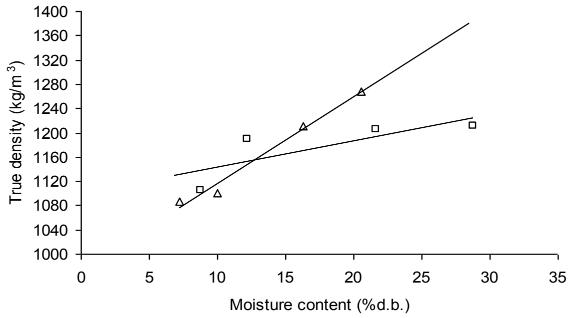

A



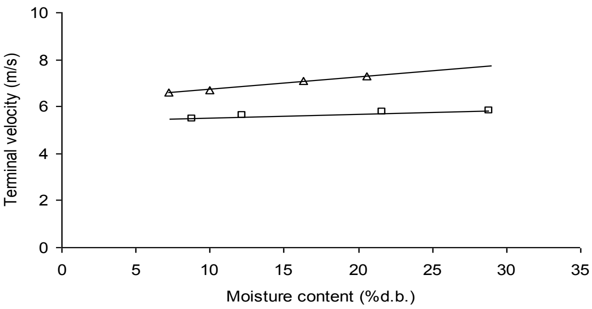

B



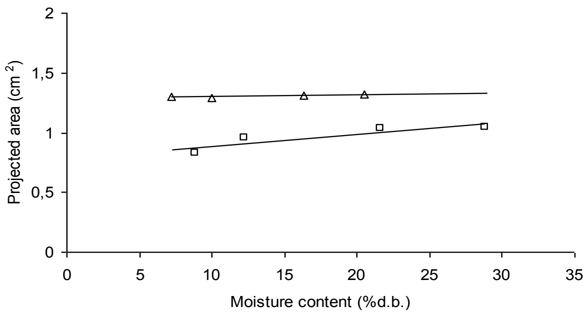

C



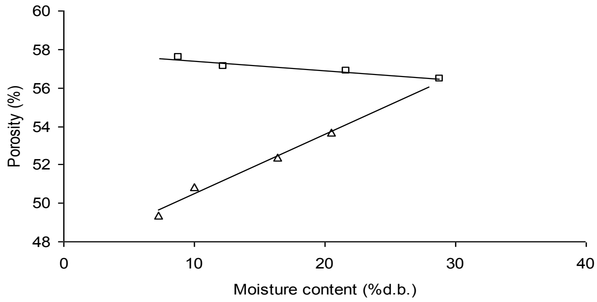

D




E




F




G

Δ Stone pine pit □□ Stone pine kernel

Figure 3

Sphericity (A), 1000 Grain Mass (B), Bulk Density (C), True Density (D), Terminal Velocity (E), Projected Area (F), Porosity (G) Variations with Moisture Content of Stone Pine Pit and Kernel

The correlation coefficient between the length and width, between length and thickness, and between length and mass were calculated as 0.286, 0.137 and 0.626 for stone pine pits at 7.25% moisture content and 0.212, 0.077 and 0.487 for stone pine kernel at 8.82% moisture content, respectively. The correlation coefficients between length and mass of stone pine pits/kernels were found significant at a 1% level.

*3.2. Sphericity*

The sphericity value of stone pine pits at different moisture content was measured as 0.5613 at 7.25%; 0.5663 at 9.96%; 0.5698 at 16.34% and 0.5717 at 20.52% moisture content, respectively (Table 1). Sphericity value for stone pine kernels were calculated as 0.4855 at 8.82%; 0.4877 at 12.24%; 0.4905 at 21.63% and 0.4956 at 28.84% moisture content, respectively (Table 1). The relationships between sphericity and moisture content of stone pine pit/kernel are given in Table 2 and Figure 3. An increasing relationship was seen between sphericity and moisture content in stone pine kernels. Desphande et al. (1993) have reported an increasing relationship between sphericity and moisture content up to moisture content of 25% in their experiments with soybeans.

Table 2
The relationships between stone pine pit/kernel properties and moisture content*

| Properties | Stone pine pit | Stone pine kernel |
|---|---|---|
| Sphericity | $\Phi_p = 0.5575 + 0.0007\, m_p (R^2 = 0.9156)$ | $\Phi_k = 0.4814 + 0.0005\, m_k (R^2 = 0.9675)$ |
| 1000 grain mass | $m_{1000\ p} = 409.41 + 11.229\, m_p (R^2 = 0.9866)$ | $m_{1000\ k} = 135.59 + 2.8107\, m_k (R^2 = 0.9996)$ |
| Bulk density | $\rho_{bp} = 534.44 + 2.4249\, m_p (R^2 = 0.9639)$ | $\rho_{bk} = 462.18 + 2.4801\, m_k (R^2 = 0.6967)$ |
| True density | $\rho_{tp} = 972.11 + 14.382\, m_p (R^2 = 0.9842)$ | $\rho_{tk} = 1100.5 + 4.2923\, m_k (R^2 = 0.6164)$ |
| Terminal velocity | $v_p = 6.1969 + 0.0537\, m_p (R^2 = 0.9985)$ | $v_k = 5.3655 + 0.0159\, m_k (R^2 = 0.882)$ |
| Projected area | $Pa_p = 1.2863 + 0.0014\, m_p (R^2 = 0.8012)$ | $Pa_k = 0.7861 + 0.01\, m_k (R^2 = 0.7909)$ |
| Porosity | $\varepsilon_p = 47.424 + 0.3067\, m_p (R^2 = 0.9781)$ | $\varepsilon_k = 57.871 - 0.0493\, m_k (R^2 = -0.9299)$ |
| Coefficient of static friction | $\mu_p = 0.2539 + 0.0105\, m_p (R^2 = 0.9078)^{**}$ | $\mu_k = 0.3664 + 0.0026\, m_k (R^2 = 0.9098)^{**}$ |
| | $\mu_p = 0.4824 + 0.0018\, m_p (R^2 = 0.8756)^{***}$ | $\mu_k = 0.4276 + 0.0017\, m_k (R^2 = 0.8229)^{***}$ |

* Moisture level for stone pine pit is 7.25% , and pine pit kernel is 8.82%.
** Galvanized steel sheet
*** Plywood sheet

*3.3. Thousand Grain Mass*

Thousand grain mass of stone pine pits and kernels at different moisture content was measured between 494.7 g and 635.5 g; 160.8 g and 216.5 g, respectively (Fig. 3). An increasing relationship was seen between 1000 kernel mass and moisture content in stone pine pits and kernels (Fig. 3), and the equations are given in Table 2. Similar results were reported by Desphande et al. (1993) and Singh and Goswami (1996) for soybeans and cumin seeds respectively.

*3.4. Bulk Density*

Bulk densities of stone pine pits at 7.25%, and 20.52 % moisture levels were 549.8 kg m$^{-3}$ and 581.7 kg m$^{-3}$, respectively (Fig. 3). In stone pine kernels; while the bulk density was 467.4 kg m$^{-3}$ at a moisture content of 8.82%, it increased to 527 kg m$^{-3}$ at a moisture content of 28.84% (Fig. 3). The relationship between bulk density and moisture content of stone pine pit/stone pine kernel is given in Table 2 and Figure 3. There is some literature that reports a positive relationship between the moisture content and bulk density of some seeds such as pumpkin, coffee and karingda (Suthar and Das 1996; Joshi et al., 1993; Chandrasekar and Visvanathan 1999). However, as the moisture content increased, the bulk density values decreased in lupin seeds, in soybean and in sunflower seeds (Dasphande et al. 1993; Gupta and Das 1997).

*3.5. True Density*

True densities of stone pine pit and kernel changed between 1087.3 kg m$^{-3}$ and 1268 kg m$^{-3}$ and 1103.9 kg m$^{-3}$ and 1210.1 kg m$^{-3}$, respectively (Fig. 3). The relationship between volume mass and the moisture content is given in Table 2. Similar results were found by other researchers (Gupta and Das 1997; Singh and Goswami 1996).

*3.6. Terminal Velocity*

Terminal velocities of stone pine pits and kernels varied between 6.59 m s$^{-1}$ and 7.29 m s$^{-1}$, 5.45 m s$^{-1}$ and 5.79 m s$^{-1}$, respectively (Fig.3). The relationship between terminal velocity and moisture content is given in Table 2. As the moisture content of grains increased, the values of terminal velocity also increased. Joshi et al. (1993) found similar results for pumpkin and lentil.

*3.7. Projected Area*

Projected areas of stone pine pit and stone pine kernel are given in Figure 3. Projected areas varied between 1.30 $cm^2$ and 1.45 $cm^2$ and 0.82 $cm^2$ and 1.05 $cm^2$ for stone pine pits and stone pine kernels, respectively. As moisture content increased, projected areas also increased. The relationship between projected area and moisture content of stone pine pits and stone pine kernel is given in Table 2.

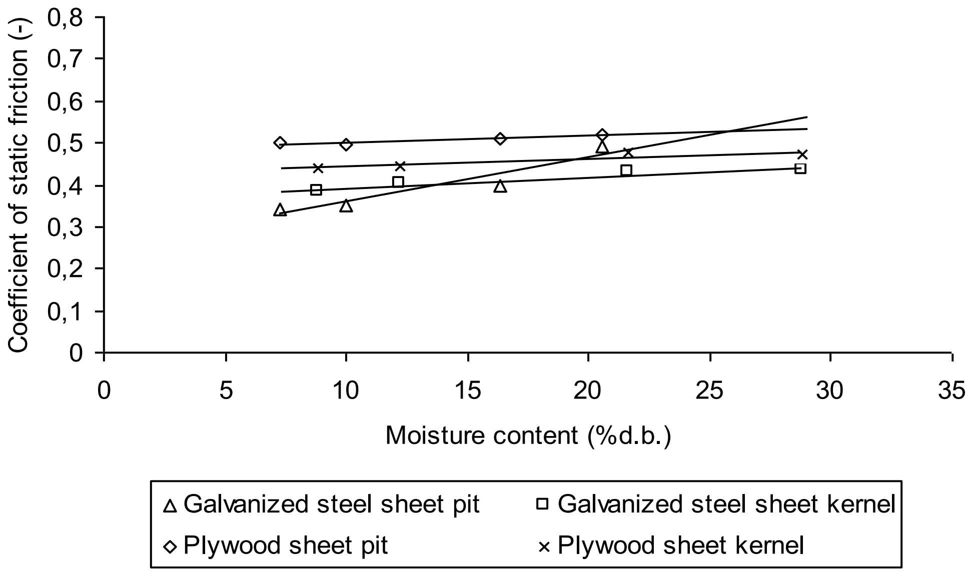



Figure 4

Coefficient of Static Friction Versus of Moisture Content

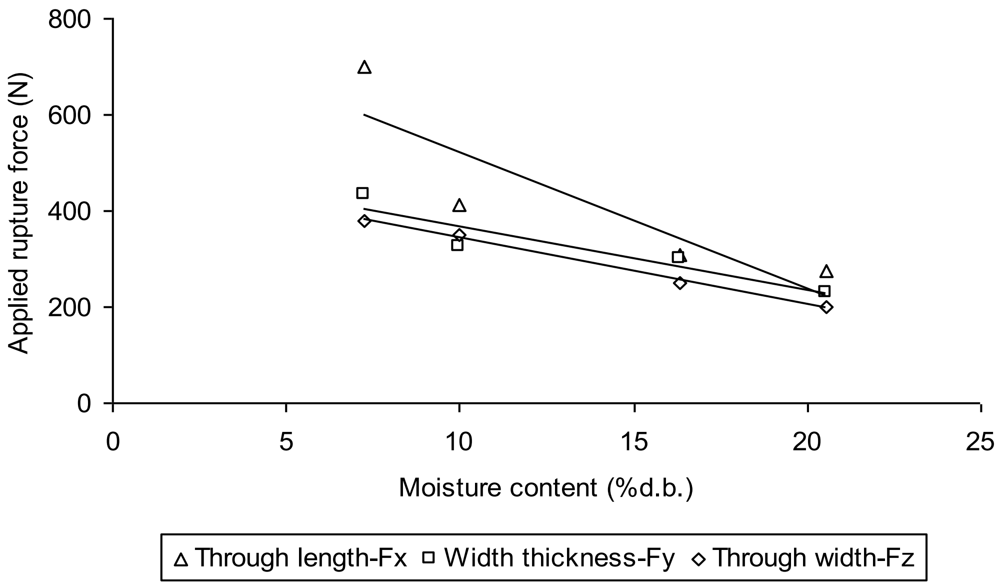



Figure 5

Variation of Rupture Force of Stone Pine Pits Versus of Moisture Content

*3.8. Porosity*

The variations of porosity values related to moisture content in stone pine pits and stone pine kernel are shown in Figure 3. The porosity values stone pine pits at moisture contents of 7.25 and 20.52 varied between 49.37% and 53.7%. The relationship between porosity value and moisture content of stone pine pit/kernel is given in Table 2. Gupta and Das (1997), for sunflower, stated that as the moisture content increased the porosity value also increased. In stone pine kernel, the porosity values at moisture contents of from 8.82% to 28.84% vary between 57.56% and 56.45%. There is a negative relationship between porosity and moisture content. Some of similar results are reported in related literature for karingda seeds, coffee, soybean and pumpkin seeds (Suthar and Das 1996; Chandrasekar and Visvanathan 1999; Desphande et al. 1993; Joshi et al. 1993).

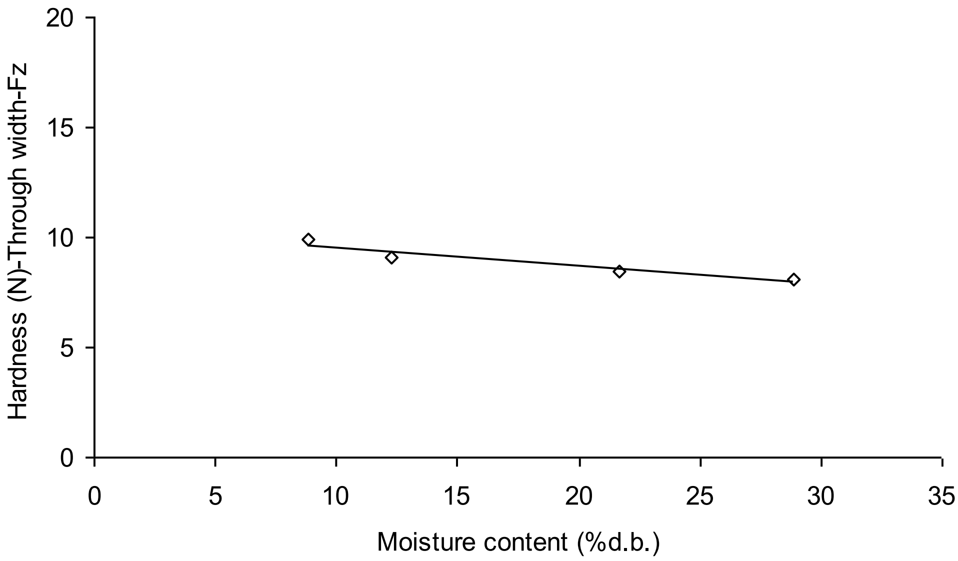



Figure 6

Variation of Hardness of Stone Pine Kernels Versus of Moisture Content

*3.9. Coefficient of Static Friction*

The variation of the coefficient of static friction with moisture content in stone pine pit and stone pine kernel is given in Figure 4 for galvanised steel sheet and plywood sheet. The relationship between coefficient of static friction and moisture content of stone pine pit/kernel is given Table 2. Joshi et al. (1993), Tsang-Mui-Chung et al. (1984) stated that as the moisture content increased, the coefficient of static friction increased.

*3.10. Rupture Strength and Hardness*

Rupture strength values of stone pine pit and hardness values stone pine kernel are given in Figure 5 and Figure 6, respectively. Rupture strength values of stone pine pits decreased as the moisture content increased. A study of Guner et al. (1999) supported this result.

In stone pine pit, force applied through length was the biggest and it was followed by the one applied through thickness and width. This difference may be attributed to physical properties of the stone pine pit. The relationship between rupture strength values and moisture content was found to be as follows:

$$F_{xp} = 803.52 - 28.11 m_p (R^2 = -0.7706) \quad (6)$$

$$F_{yp} = 497 - 12.945 m_p (R^2 = -0.8653) \quad (7)$$

$$F_{zp} = 483.61 - 13.865\ m_p (R^2 = -0.9964) \quad (8)$$

The hardness value of stone pine kernel decreased as the moisture content increased. The relationship between hardness values and moisture content was found to be as follows:

$$H_k = 10.375 - 0.0825 m_k (R^2 = -0.9167) \quad (9)$$

As a result, the relationship between moisture content and physical properties of stone pine was researched. Sphericity values of stone pine pit showed a slight decreasing trend depending on moisture content, but in pine kernel, they increased with increasing amount of moisture content. Also 1000 grain mass, terminal velocity, bulk and true density and projected area increased with moisture content. A negative relationship was found between rupture strength values of stone pine pit and stone pine kernel and moisture content. While the force applied through length was found to be highest in stone pine pit, it was found to be highest through thickness in stone pine kernel.

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