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Effect of Ultrasound on Mechanical Properties of Walnut

Ebrahim Biabani-Agdam[1], Mohammad Hadi Khoshtaghaza[1✉], Gholamhassan Najafi[1]

[1] Biosystems Engineering Department, Tarbiat Modares University, Tehran, Iran.

✉ Corresponding author: khoshtag@modares.ac.ir

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ABSTRACT

Walnut mechanical properties are an appropriate criterion for designing and adjusting the various parts of harvesting machines that are in contact with walnut. In this research, the aim is to find the effect of ultrasound factors on walnut mechanical properties to reduce walnut rupture force and energy. Walnuts were treated with three ultrasound time duration (5, 10, and 15 min) and three ultrasound bath temperatures (20, 35, and 50ºC). After the walnuts were treated by ultrasound factors, wet and dried walnut samples were loaded at three loading speeds (0.5, 1.5, 2.5 mm/s) along width and length direction for determination of mechanical properties. Regarding the ANOVA results, the ultrasound time factor had the most effect on the rupture force, energy, and toughness. Results showed walnut ultrasound-treated samples had minimum rupture force and energy. Also, rupture force, required energy, and toughness decreased with increasing ultrasound bath temperature and the ultrasound time duration. The minimum walnut rupture force was obtained at 62.7 N in 25 min ultrasound time duration, 50ºC bath temperature, 1.5 mm/s loading speed, and width loading direction for wet walnut sample.

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INTRODUCTION

Walnut has high levels of oil, proteins, vitamins, and nutrients and high medical importance (Colarič et al., 2006). Iran nearly provides 11% of world walnut production (0.45 million tons) and is the world's third largest producer of walnut. Therefore, it is necessary to develop processing and packaging systems for this valuable crop. One of the most important and sensitive steps after walnut harvesting is separation of the kernel from its hell. In Iran, harvesting and shelling walnut are still carried out manually, which raises production costs and causes damage and broken kernels. In this regard, determining physical and mechanical properties of walnut is necessary for designing harvesting equipment's and developing postharvest processes such as cleaning, grading, sorting, and transporting (Mohapatra & Bal, 2007).

Ultrasound treatment has been widely used in food processing recently. Low frequency-high intensity ultrasound produces strong shear and mechanical forces in ambient fluids that cause mechanical or chemical/biochemical changes and biological cell rupture (Verhaagen & Rivas, 2016). These effects arise principally from the phenomenon known as cavitation which can scour surfaces and damage cellular material. In a study, it was shown that ultrasound treatment effected the mechanical properties of strawberries, and increasing the frequency caused increasing texture stiffness and quality (Cao et al., 2010). The use of ultrasound as a new non-thermal technology caused breaking seed dormancy and increasing germination percentage and facilitating seedling exit from the shell (Yaldagard et al., 2008). In previous study, it was found that the use of ultrasound effect on kernel extracting quality of walnut so that walnut ultrasound treated samples had the best quality kernel extraction (Biabani Agdam et al., 2021).

Kabas and Vladut (2016) found that rupture force of pecan nuts decreased with an increase moisture content. Also, it was founded that loading direction is an important parameter that affects the mechanical properties of walnut and minimum walnut rupture force, and the best kernel extraction quality was obtained in width loading direction (M. Koyuncu et al., 2004; M. A. Koyuncu et al., 2004; Sharifian & Derafshi, 2008). Altuntas and Erkol (2011) reported highest rupture force of walnut were obtained in width loading direction in all moisture contents(Altuntas & Erkol, 2011). According to the difference walnut variety samples (in geometric shape and sphericity coefficient) which used in two researches, the results were not consistent. Rupture force and energy of various nut crops decrease by increasing moisture content (Aktas et al., 2007; Carcel et al., 2012; Güner et al., 2003; Ince et al., 2009; Kacal and Koyuncu, 2017)

In this research, the objectives are to find the effect of ultrasound factors on walnut mechanical properties and to reduce walnut rupture force and energy by using ultrasound technology .

MATERIALS AND METHODS

Walnut paper variety was selected from Qazvin province. Walnuts with geometric mean diameter (Dg) of 37-38 mm were chosen for all the experiments. To determine initial moisture content of the walnuts, the samples were dried in an oven at 105 °C for 24 h. Initial moisture content was found 5.5 (%w.b).

Ultrasounds bath system (D-78224 Singen/htw, Elma, Germany) was used with a nominal frequency of 50 kHz and power of 1000 W. In this research, based on the pretest results and previous studies (Cao et al., 2010; Entezari et al., 2004) walnuts were treated with three ultrasound time duration (5, 10, and 15 min) and three ultrasound bath temperatures (20, 35 and 50 ºC). Walnut density is lower than water density, likewise walnuts floated in water, to solve this problem a grid container inside the compartment was used (Figure.1). Moisture content of the walnuts after ultrasound treatment was 8.8 (%w.b).

Figure 1. Perform of waves on walnut samples

After the walnuts were treated by ultrasound factors, a material testing machine (H50 K-S, Hounsfield, England) was used to determine the mechanical properties of the walnuts. The walnuts were placed between two plats (Figure.2), and loaded at three loading speeds (0.5, 1.5, 2.5 mm/s). Mechanical properties were applied along with X and Y axes. The X-axis was in longitudinal axis through the hilum to the tip (length) and the Y-axis.

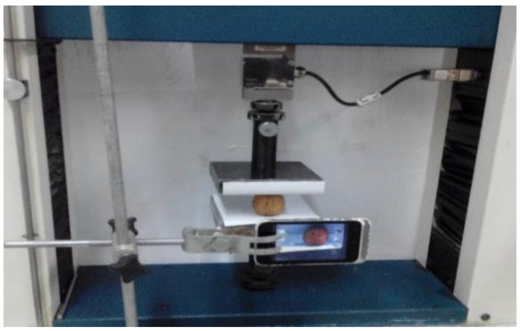

Figure 2. Walnut loading direction

was in transverse axis (width) at right angles to the X-axis. To determine the effect of moisture content on mechanical properties, some of the walnuts were directly (8.8 (%w.b)) loaded, and other walnuts were dried in an oven to reduce the initial moisture content (5.5(w.b)) and then were loaded. Rupture point was determined from the force-deformation curve .The rupture energy was determined by measuring the area under the force–deformation curves. Toughness was calculated by the following equation (Khazaei et al., 2002).

$$P = \frac{E}{V} \qquad (1)$$

Where P is the toughness (J/mm^3) and E is the rupture energy (J) and V is volume (mm^3).

Design expert 7 statistical software package and central composite design (CCD) of resound surface method was used to analyze the experimental data. The effect of independent variables x_1 (loading speed), x_2 (ultrasound bath temperature), x_3(ultrasound time duration) each at three levels, and x_4 (loading direction) and x_5 (moisture) each at two levels were evaluated. In this study, 80 experiments with 6 center points were performed.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) is presented in Table 1. Results indicated that loading speed, ultrasound time duration, and loading direction had highly significant effect ($P < 0.01$) on mechanical properties and ultrasound bath temperature had significant effect ($P < 0.05$) on rupture force and energy. Moisture content had highly significant effect ($P < 0.01$) on rupture force and toughness. Also, ultrasound bath temperature hadn't significant effect on toughness. Regarding the sum of squares of ANOVA results, the ultrasound time duration factor had the most effect. The interaction relationships of loading speed with the loading direction had significant effect on mechanical properties. The interaction relationships of loading speed with the ultrasound bath temperature had significant effect on rupture force and toughness. After omitting the non-significant coefficients, the final models for mechanical properties were obtained (Table 2). The minimum walnut rupture force was obtained 62.7 N in 25 min ultrasound time duration, 50 ºC bath temperature, 1.5 mm s^{-1} loading speed, width loading direction, and wet walnut. Minimum required energy, and toughness were obtained 96.76 mJ and 4.98 J/mm^3 in 25 min ultrasound time duration, 50 ºC bath temperature, 0.5 mm/s loading speed, width loading direction, and wet walnut.

Table 1. Analysis of variance for mechanical properties of walnut

		Sum of squares		
Source	df	rupture force(N)	rupture energy(mJ)	Toughness (J/mm^3)
Model	18	6562.98**	39782.62**	96.2**
x_1	1	800.51**	1696.77**	6.75**
x_2	1	101.04*	1176.25*	1.29 ^{ns}
x_3	1	2582.51**	12453.49**	36.16**
x_4	1	944.13**	12141.36**	27.95**
x_5	1	385.02**	4521.48^{ns}	8.78**
x_1x_2	1	31.88 ^{ns}	215.7 ^{ns}	0.3 ^{ns}
x_1x_3	1	12.44 ^{ns}	1218.2*	2.1*
x_1x_4	1	142.07*	1411.34**	3.98**
x_1x_5	1	11 ^{ns}	49.46^{ns}	0.1 ^{ns}
x_2x^3	1	1.91 ^{ns}	134.4^{ns}	0.2 ^{ns}
x_2x_4	1	1.18 ^{ns}	133.19^{ns}	0.25^{ns}
x_2x_5	1	8.3 ^{ns}	70.89^{ns}	0.072 ^{ns}
x_3x_4	1	88.32*	239.86^{ns}	0.47^{ns}
x_3x_5	1	4.43 ^{ns}	99.32^{ns}	0.027 ^{ns}
x_4x_5	1	66.24 ^{ns}	835.08*	2.02*
x_1^2	1	659.82**	746.69*	1.22 ^{ns}
x_2^2	1	10.06 ^{ns}	9.2 ^{ns}	0.054 ^{ns}
x_3^2	1	32.97 ^{ns}	539.89^{ns}	1.11 ^{ns}
Residual	61	21.68	186.64	29.38
Lack of Fit	41	21.73 ^{ns}	215.76^{ns}	20.38 ^{ns}
Pure Error	20	21.58 ^{ns}	126.95 ^{ns}	8.55 ^{ns}

^{ns} not significant, * significant at 5% level, and ** significant at 1% level

x_1 (loading speed), x_2 (ultrasound bath temperature), x_3(ultrasound time duration), x_4 (loading direction), x_5 (moisture content)

Table 2. Mechanical property models based on significant factors

source	**R^2**	**C.V**	**MODEL**
Rupture force	0.83	5.81	$Y_1=54 + 11.50x_1 – 3x_2 + 2.5x_3 - 23.75x_4 -6.75x_5 -5.5x_1x_4 -2.35x_4x_5 - 4.5x_1^2$
Rupture energy	0.77	9.77	$Y_2 = 133.84 + 6.51x_1 − 5.42x_2 - 17.64x_3 – 12.32 x_4 +7.52 x_5 +5.94 x_1x_4 –3.23x_4x_5 + 11.87x_1^2$
Toughness	0.76	9.62	$Y_3 = 7 + 0.41x_1 - 0.95x_3 – 0.59 x_4 +0.33 x_5 -0.26 x_1x_4 -0.32x_1x_5 - 0.16x_4x_5$

Figure 3 shows mean values of mechanical properties in different ultrasound time duration and different ultrasound bath temperature. Rupture force, required energy, and toughness were decreased with increasing ultrasound bath temperature and the time ultrasound duration. These results are due to acoustic cavitation that cause, texture of the sample becomes softer (Zhang et al., 2017). Ultrasound time duration factor had the most changes which indicates that this factor is more important than ultrasound bath temperature. These results are consistent with the study which showed ultrasound treatment caused increasing germination percentage and seedling exit from the shell (Yaldagard et al., 2008). Because of reducing the rupture force by increasing bath temperature and ultrasound time duration with same deformation, the required energy was declined. Thus, toughness was reduced by increasing bath temperature and ultrasound time duration with same deformation.

Figure 4 shows the contour plot of loading direction and moisture content on rupture energy and toughness. Minimum required energy, and toughness was obtained in the width loading direction for wet walnut. Kabas and Vladut (2016) found that at higher moisture content the shell of the walnut become soft and separation of kernel from its shell gets easier. For this reason, more kernel extraction quality was found in samples with high moisture content.

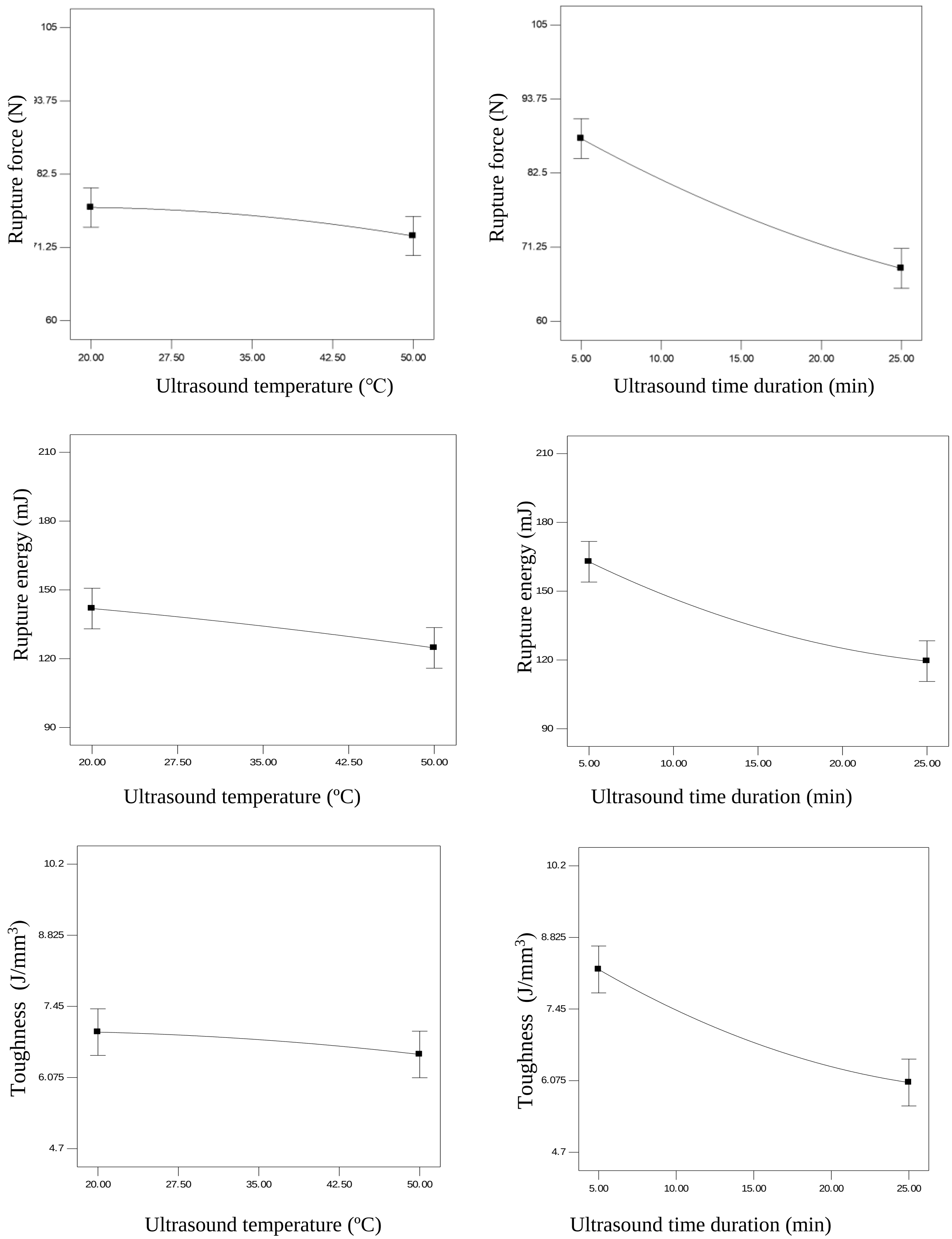

Figure 3. Mean values of rupture force, required energy, and toughness compressed at different ultrasound time duration and different ultrasound bath temperature.

The interaction effects of loading speed and direction on mechanical properties were shown in Figure. 5 Rupture force was decreased by increasing loading speed from 0.5 to 1.5 mm/s and increased by increasing loading speed from 1.5 to 2.5 mm/s in both loading directions. This phenomenon has been observed in most biological products that exhibit hardness behavior by increasing loading speed. For example, in a study on walnuts at loading speeds of 50, 200, and 500 mm/min, the rupture force increased by increasing loading speed (Sharifian and Derafshi, 2008). Rupture energy and toughness decreased in length loading direction by increasing loading speed from 0.5 to 1.5 mm/s and then increased. But in width direction loading increased by increasing loading speed from 0.5 to 2.5 mm/s. In addition, rupture force, energy, and toughness were higher in the length loading direction compared with width loading direction under the same conditions. Sharifian and Derafshi (2008) found similar result that minimum walnut rupture force was obtained in width loading direction.

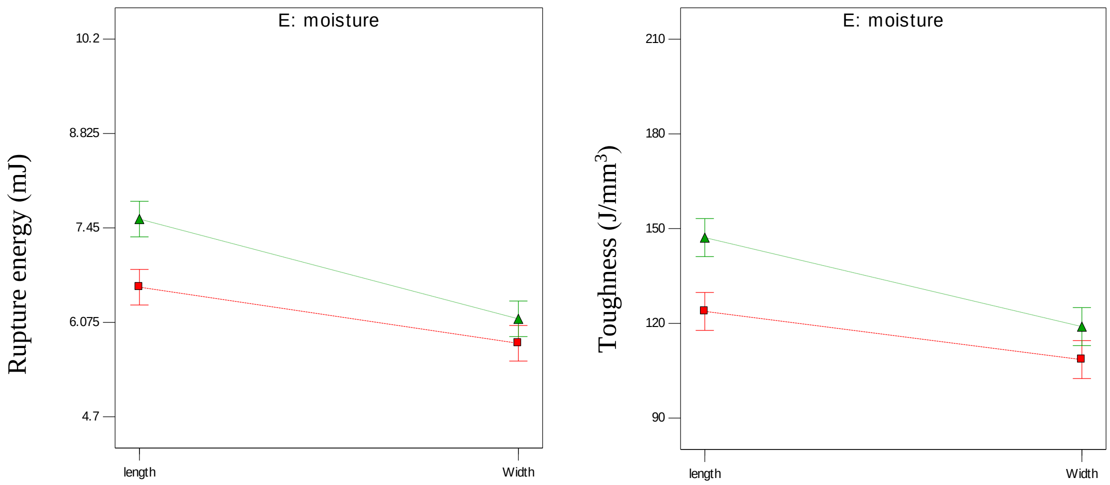

Figure 4. Interaction effect of loading direction and moisture content on rupture energy and toughness (■ Wet walnut ▲ Dried walnut)

Because of the process is carried out in water, in order to find the water effect on mechanical properties, walnuts under optimum ultrasound condition (62.07 N rupture force, at 1.3 mm /s loading speed, 25 min ultrasound duration, 50 ºC bath temperature, and length loading direction for wet walnut), wet samples (soaked in water without ultrasound treatment) and control samples (samples that have not been soaked in water) were loaded. The results of mean values were showed in Table 3. There is a significant difference between control, wet samples, and ultrasound optimal point in rupture force. Ultrasound treatment reduced rupture force, required energy, and this result could be advised for the cracking walnut processing.

Table 3. Walnut mechanical properties for control, wetted and ultrasound samples at optimal point

sample	rupture force (N)	rupture energy (mJ)	Toughness (J/mm^3)
Control	214^a	274.89^a	13.09^a
wetted by water	153^b	235.6^a	12.4^a
Optimized ultrasound	62.07^c	96.76^b	4.98^b

In each column values assigned with different letters are significantly different ($p < 0.05$).

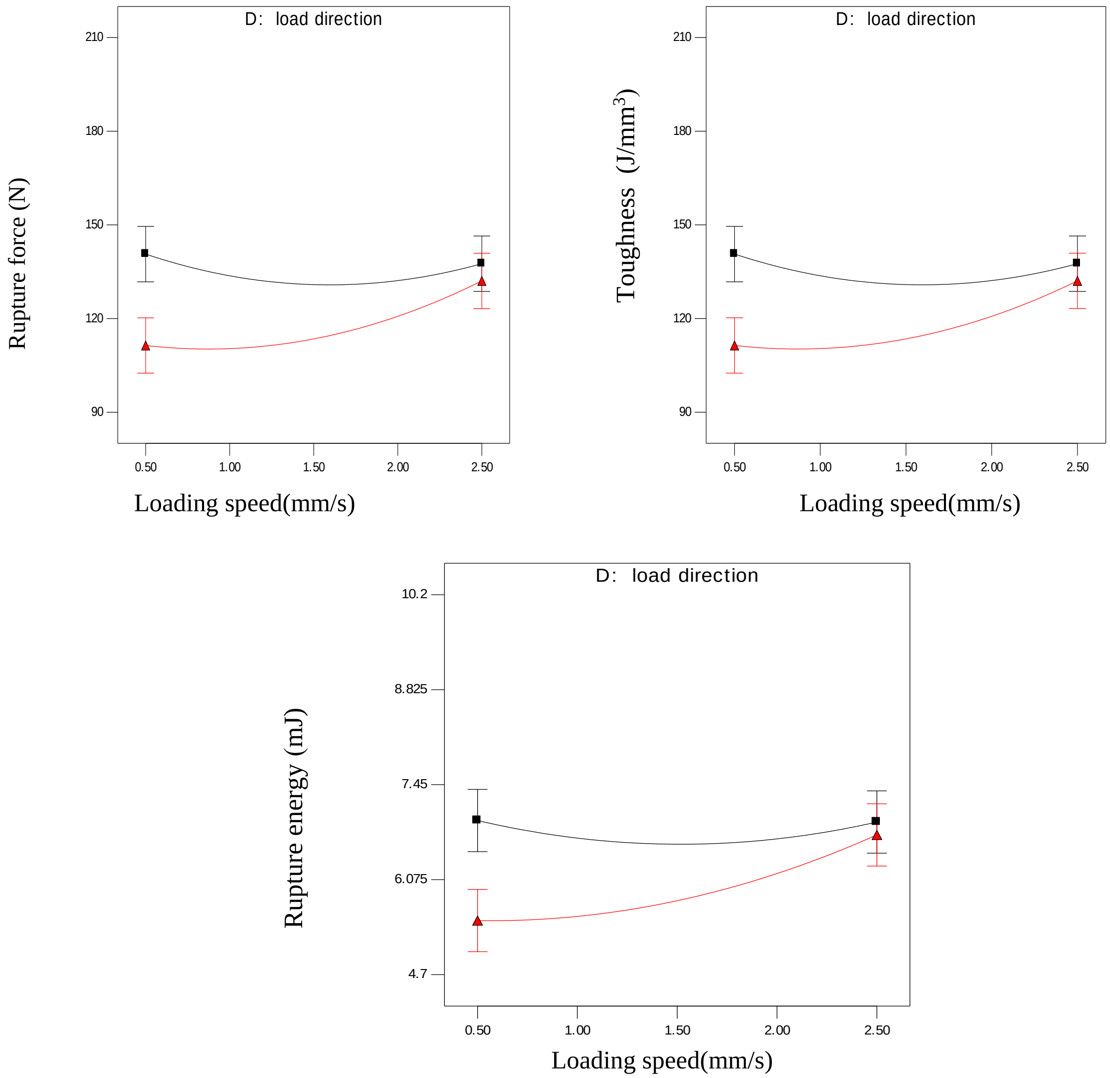

Figure 5. Interaction effect of loading speed and direction on mechanical properties of walnut
(■ Longitudinal loading ▲ Latitudinal loading)

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