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Original Research Article

Physical and Mechanical Properties of Watermelon Rind

Wan Mohd Fariz Wan Azman, Asnawi Shahar, Saiful Azwan Azizam, Afiqah Aina Rahim

Engineering Research Central, MARDI Headquarters, Persiaran MARDI-UPM, 43400, Serdang, Selangor, Malaysia, wmfariz@mardi.gov.my

*Corresponding author: Wan Mohd Fariz, W. A.; Engineering Research Central, MARDI Headquarters, Persiaran MARDI-UPM, 43400, Serdang, Selangor, Malaysia; wmfariz@mardi.gov.my

Abstract: Watermelon rind is the toughest part of the whole fruit structure and usually peeled for processing purposes. A study was conducted to determine the physical and mechanical properties of watermelon rind to provide a reference for peeling process parameters to improve the efficiency of the process. A physical examination was conducted to determine the overall watermelon length and width, and rind thickness at different positions. The rind rupture force test was conducted at different penetration angles (0.0°, 22.5°, 45.0°, and 67.6°). The rind thickness was 1.46 ± 0.27cm (P<0.01). Based on visual observation, the differences in watermelon size affect the rind thickness. The rind thickness has a random distribution at different positions of the rind (P>0.01). Meanwhile, the rupture force showed that the direction of penetration angle significantly affects the rupture force value obtained (P<0.01), and it was directly proportional to the increase of penetration angles which ranged between 21.48N to 24.25N. Hence, the watermelon size and penetration angle factors should be considered before conducting the peeling process to ensure the process is run at an optimal level.

Keywords: watermelon; rind; thickness; rupture force; penetration angle

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1. Introduction

A tropical fruit known as a watermelon (*Citrullus lanatus*) may be found almost everywhere in Southeast Asia and Africa (Koocheki *et al*. 2007). It has a large size and oval, round, or oblong shape that belongs to the cucumber family (Cucurbitacea). The rind has a smooth skin with dark green colour or occasionally pale green streaks that turn yellowish-green when mature depending on the type of variety. Watermelon is a high-vitamin food that is frequently served as an appetiser or snack, depending on how it is prepared (Kerje & Grum 2000). It is also processed into juices or jams (Fundo *et al*., 2018). Watermelon is very well known, it has been described as a significant source of phytochemicals with possible health advantages, which are often linked to its high antioxidant activity, owing to the phenolic part of the plant (Maietti *et al*., 2012).

Watermelon can be categorised into three main parts which are the flesh, seed, and rind. It contains approximately 68% of flesh, 30% of rind, and 2% of seeds from the total weight (Kumar, 1985). The rind has 95% water content, thus making it susceptible to deterioration (Athmaselvi *et al*., 2012). Therefore, the watermelon fruit cannot be stored for a long time after it is harvested. In order to prevent the watermelon from being damaged and wasted, the best solution is via processing the fruit into a new watermelon-based product that can be stored for a long time or shelf stable. In producing watermelon-based products, it needs to undergo several processes including peeling. A study needs to be conducted to determine the physical and mechanical properties of watermelon rind to provide reference for the peeling process parameters in improving process efficiency.

Peeling is a method of removing the inedible or unpleasant rind or outer layer from the flesh. Generally, peeling losses must be minimised by removing as little underlying flesh as possible while maintaining a clean peeled surface. There were various methods for the peeling process such as flash steam peeling, knife peeling, abrasion peeling, caustic peeling and flame peeling. The most widely used method is knife peeling or also known as mechanical peeling (Schmilovitch, 2015) and commonly used for peeling watermelons. Further, the efficiency of mechanical peeling depends on the effect of acting force on the cutting tool. The useful forces, such as rupture force is critical in designing cutting tool. Field phenotyping of rind rupture force is simple to achieve; for example, at the commercial level, the texture analyser device (TA-XT Plus) was frequently utilised for quick evaluation in apples (Li *et al*., 2017), and tomatoes (Wang *et al*. 2009). Puncture, compression, and cutting of the exterior rind are some of the main experimental modes (Chen & Opara, 2013), for the determination of rind rupture force which usually uses puncture mode (Jing *et al*., 2017). Over the last few years, researchers have focused more on watermelon rind hardness, rind cracking susceptibility, and resistance. However, the principle of the peeling method involves the position of the cutting blade which affects the cutting angle obtained. In this case, there is no specific information on the effect of cutting angle force on the watermelon rind.

The main purpose of this study was to determine the physical and mechanical properties of watermelon rind to provide a reference for the peeling process parameters in improving process efficiency. In this case, the focus was to determine the effect of cutting angle force on the watermelon rind. Physical examination (length, width and rind thickness) was performed as a guideline for the peeling process and as information for machine design.

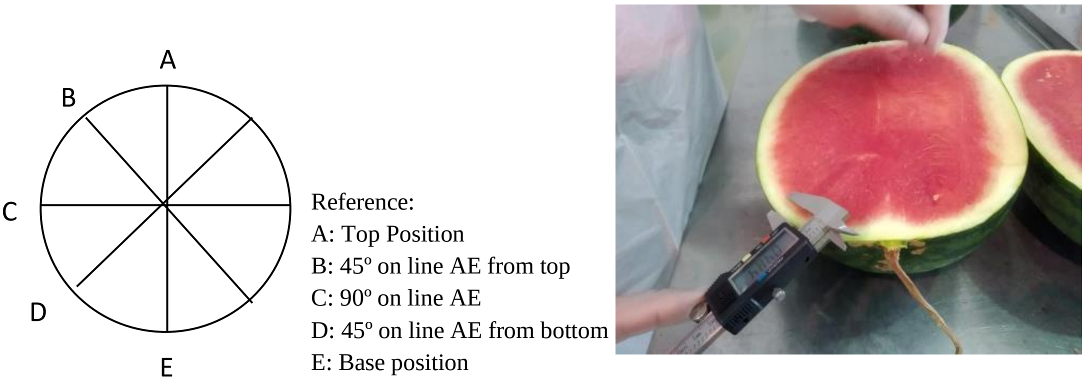
2. Materials and Methods

2.1. Material Preparation

For fruit selection, a total of 20 watermelons (Seedless Watermelon: F1 HYBRID) were randomly purchased from a local market at Pasar Borong Selangor, Malaysia. All watermelons were ripe (ready to eat), defect- or injury-free, and L -L-sized fruit category (FAMA, 2000). All fruits were weighed using a digital weighing (DE-A11N, Kern, German) scale of 100 kg and measured the size (major and minor circumferences; major and minor diameters) using measuring tape.

2.2. Determination of Watermelon Rind Thickness

Watermelon samples of 20 were cut lengthwise gently into 2 sections (Davis & Penelope, 2005). The rind thickness was measured using a digital Vernier calliper (SEB-DC-024, SEB, China) at 5 different locations (A, B, C, D, E) as shown in Figure 1a. The purpose of collecting rind thickness at several positions was to examine size variations. The rind thickness measurements include green outer skin and white flesh (Figure 1b). Each measurement was taken three times to obtain an average value for each watermelon sample.



(a) (b)

Figure 1. (a) Rind thickness measuring position; (b) Rind thickness measuring process

2.3. Determination of Watermelon Rind and Flesh Ratio

Watermelon samples (n=17) from previously cut fruit were peeled using a knife slowly and carefully until the red flesh appeared. The peeled rind and the red flesh were weighed using a digital weighing scale of 100 kg (DE-A11N, Kern, German). The rind and flesh weight ratio (Equation 1), and flesh recovery (Equation 2) were determined.

$$\text{Ratio rind/flesh} = \frac{\text{rind weight (kg)}}{\text{watermelon flesh (kg)}} \quad (1)$$

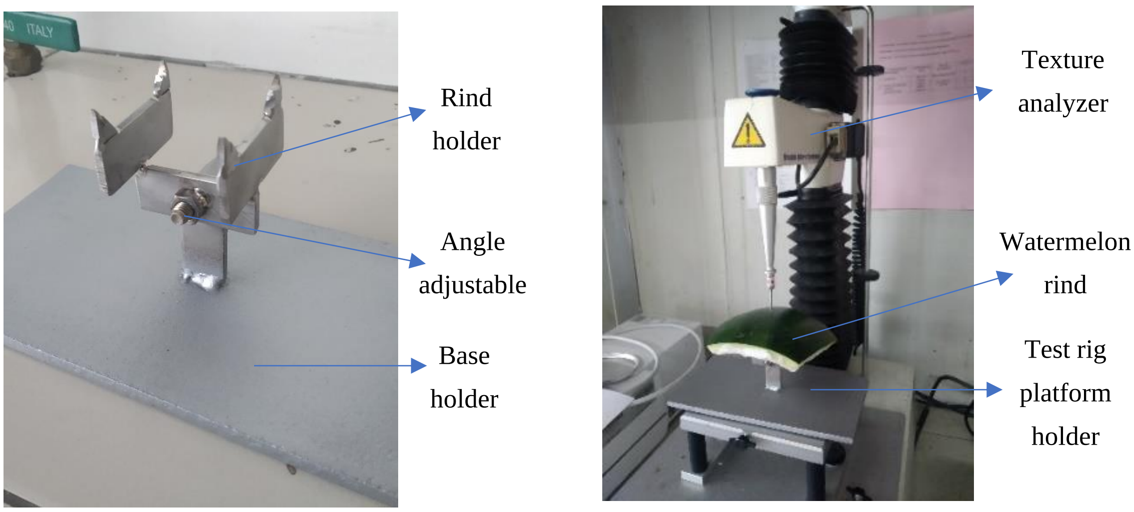
$$\text{Flesh recovery (\%)} = \frac{\text{Watermelon flesh (kg)}}{\text{Watermelon weight (kg)}} \times 100\% \quad (2)$$

2.4. Determination of Watermelon Rind Rupture Force

Rind samples of 15 were prepared with a size of 50mm X 50mm in an equal square shape, and the flesh was gently removed using a scraper. An adjustable test rig was built as a watermelon rind platform holder. The test rig platform holder is specially designed so that the degree of tilt can be adjusted and it can be placed on a Texture Analyser (TA.XTplus, Stable Micro Systems, UK) platform during the test (Figure 2a). The rind sample was kept horizontal (0º of tilt angle) on the test rig holder during the first penetration test process. The rupture force assessment of watermelon rind was conducted using a texture analyser as shown in Figure 2b. A puncture test was carried out with a stainless-steel cylinder probe with a diameter of 2 mm that was connected to a computer and digitally recorded. The machine was set up with a 2 cm penetration depth with a speed of 120 mm/min. Rico *et al*. (2006) used the same approach for the rupture test. The load value result was reported in force (N). The penetration test was applied at 6 different points and the first curved peak height exhibited by probe puncture was rupture force (N). Then, the penetration test was repeated with different tilt angles (22.5º, 45º, 67.5º) and each test was repeated 6 times.

2.5. Determination of Moisture Content

The moisture content (MC%) assessment was conducted using a moisture analyser (HE53 230V, METTLER TOLEDO, USA). Each assessment was conducted before the penetration test (15 Samples). The observation was done in duplicates for each sample, and the average was reported.



(a) (b)

Figure 2. (a) The test rig platform holder; (b) Penetration test using texture analyser

2.6. Statistical Analysis

Using the Statistical Analysis System (SAS 9.0) computing tool, experimental data were analysed using Analysis of Variance (ANOVA), and significant differences between means were found using the Duncan Multiple Range Test (DMRT) at $p \leq 0.01$.

3. Results and Discussions

3.1. Physical Properties of Watermelon

The determination of moisture content (MC) was important because it affects the rind strength which in turn influenced the peeling capability. Lixian (2016) indicated that moisture content affects the strength of stalk rind, and Sara (2014) also reported the increment of moisture content causing the strength of the fruit rind to decrease. Therefore, the determination of material water content is very important as a reference and control before the strength study is conducted. Table 1 shows the result of water activity and moisture content of the watermelon rind (outer skin and white rind). The white part of the rind showed higher moisture content (94.83±1.02%) as compared to the outer skin (89.31±2.21%) with a water activity of 0.81±0.01 and 0.78±0.01, respectively. The lipophilic material that covers fruit surfaces typically prevents water loss from hypodermal regions. However, cuticular transpiration during storage causes the water in the hypodermal tissues to gradually disappear, which compromises the fruit's anti-desiccation system (Riederer & Schreiber, 2001). As a result, the skin moisture content is lower than the rind. Nevertheless, the rind moisture content obtained is almost the same as reported by Nur Farah Hani *et al.* (2014) which was 94.60%, 94.62% by Md. Masudul and Iqbal (2015), and 93.8% by Bawa and Bains (1977) with a significance of $P > 0.01$. It also found that the watermelon rind has the same moisture content as the raw red watermelon rind (94.83%) as reported by Sanwiriya and Suleiman (2019).

Table 1. Water activity and moisture content of watermelon rind (outer skin and white rind).

	Water activity (a_w)	**Moisture content (MC%)**
Outer skin (Green)	0.78±0.01	89.31±2.21
Rind (White)	0.81±0.01	94.83±1.02

According to Table 2, the obtained rind thickness range was 0.90 cm to 2.30 cm (μ: 1.46±0.27 cm), which is higher than the range reported by Tiantian *et al.* (2021), which was 0.59 cm to 1.12 cm and also higher than reported by Davis and Penelope (2005) when compared to the average value (μ:1.20 cm). The rind thickness varies due to varieties (Tiantian *et al.*, 2021). Furthermore, the gourd rootstock grafting technique also influences the rind's thickness, which increases the skin's thickness (Davis & Penelope, 2005). Naturally, watermelon is oval in shape; as the results showed the obtained circumference of watermelon was almost the same as the SS5244 variety and but smaller than the SF800 variety when compared to the findings by Davis and Penelope (2005). In terms of diameter obtained, the F1 HYBRID variety is smaller than the SS5244 and SF800 varieties. The average weight of watermelon obtained was 6.75±1.51kg which is almost similar to the SS5244 variety (6.50 kg), but much lower when compared with the SF800 variety (9.00kg). The determination of rind thickness and size parameters is very useful as a reference for the peeling process to reduce losses and increase peeling efficiency. Table 3 shows the watermelon rind and flesh ratio and flesh recovery. The rind flesh ratio and flesh recovery obtained were 49:100 and 60.83±9.49%, respectively which is slightly less than that obtained by Kumar (1985) and Nur Farah Hani (2015) was around 68%.

Table 2. Physical properties of watermelon in average value (μ).

	F1 HYBRID (seedless)	**Davis and Penelope (2005)**	
		SF800	**SS5244 (seedless)**
Rind thickness (cm)	1.46±0.27	1.14	1.20
Weight (kg)	6.75±1.51	9.00	6.50
Circumference (cm)	69.39±4.62	70.00	69.90
Length (cm)	27.33±3.54	33.10	25.70
Diameter (cm)	20.96±3.55	22.30	22.20

Table 3. The watermelon rind and flesh ratio.

Rind / fruit (kg)	**Flesh / fruit (kg)**	**Ratio rind/flesh**	**Flesh recovery (%)**
2.26±0.46	4.58±0.58	49:100	60.83±9.49

A subsequent study was performed to identify whether differences in physical characteristics has an influence on rind thickness. Table 4 shows the correlation among watermelon physical properties (Rind thickness, Rind thickness position, Weight, Circumference, Diameter, and Length). The results showed that the rind position does not correlate with the rind thickness and all other size measurements (P>0.01). This indicated that the overall rind thickness of the watermelon is random according to the position. Furthermore, the rind thickness showed a positive Pearson correlation between weight, circumference, diameter and length. As a result, an increase in value for other physical factors will result in a thicker rind. The larger the size of the fruit, the thickness of the rind will increase. To date, there is lack of studies on the physical relationship with rind thickness to be used as a comparative study. Most research reports are focused on the effects of grafting techniques, nutrition on the physicality of the fruit.

Table 4. Correlation among physical properties of watermelon (P value).

Physical Properties	Pearson Correlation					
	Rind thickness	Rind thickness position	Weight	Minor circumference	diameter	Major diameter
Rind thickness	1	0.290	.521**	.504**	.688**	.670**
Rind thickness position	0.290	1	0.000	0.000	0.000	0.000
Weight	.521**	0.000	1	.977**	.964**	.913**
Circumference	.504**	0.000	.977**	1	.959**	.907**
Diameter	.688**	0.000	.964**	.959**	1	.979**
Length	.670**	0.000	.913**	.907**	.979**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.2. The Rupture Force of Watermelon Rind

Figure 3 exhibited that the direction of penetration angle was significantly affects the rupture force value obtained ($P<0.01$). It is directly proportional to the increase of penetration angles with a correlation value of $R^2 = 0.99$ and with a significant difference of $P<0.01$ (F-value = 17.52). The highest rupture force (24.25±0.87N) occurred at a penetration angle of 67.5º, followed by 22.95±1.31N, 22.09±0.51N and 21.48±0.80N at 45º, 22.5º and 0º. From the results, a quadratic equation (Equation 3) was developed which exhibited the correlation between rupture force and penetration angle. However, the value obtained was lower than the value reported by Emadi (2009) which was 175 N for peeled watermelon rind and 183 N for unpeeled watermelon rind. In addition, Emadi (2009) reported that the rapture force of peeled rind was lower than unpeeled rind. Referring to the results of the rind moisture content obtained previously, the outer skin has lower moisture content as compared to the white rind. This clarified why the peeled rind has lower rapture force compared to the rind of an unpeeled watermelon due to the presence of high moisture content, which reduced the rind strength. Sara (2014). Therefore, the presence of outer skin affects the rapture force of the whole watermelon rind since it has different moisture content. Furthermore, this situation also answered the question of why the increase in penetration angle caused the rapture force to increase. This is due to the increase in the penetration angle causing the contact surface area between the punch and the outer skin surface to also increase and indirectly increase the rapture force.

$$y = 0.1723x^2 + 0.0565x + 21.26 \quad (3)$$

Whereby (y) refer to rupture force, (x) refer to penetration angle.

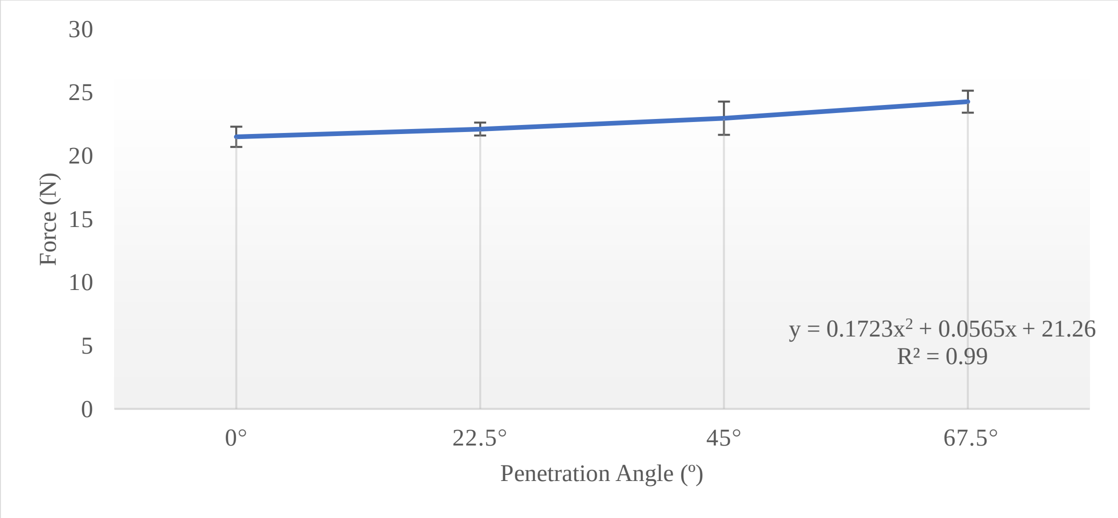


Figure 3. The rupture force (N) at different penetration angles (º). The data values were expressed as mean ± SD; *n* = 8.

The result of multiple comparisons of penetration angle to rupture force (Table 5) showed that the penetration angle at 0.0º and 22.5º has a significant difference of rupture force to penetration angle at 67.6º (P<0.01). However, the penetration angle at 0.0º had no significant difference in rupture force to penetration angle at 22.5º and 45.0º (P>0.01). In addition, the penetration angle at 45.0º showed no significant difference in rupture force at all other penetration angles. This indicated that the penetration angle of 22.5º and 45.0º did not show a significant difference in the resulting rapture force.

Table 5. Multiple comparisons of penetration angle of rupture force

Penetration angle		**Mean Difference (I-J)**	**Std. Error**	**P Value**
Group (I)	**Group (J)**			
0.0º	22.5º	-62.69	49.17	0.59
	45.0º	-149.94	58.40	0.08
	67.6º	-282.88750*	40.92	0.00
22.5º	0.0º	62.69	49.17	0.59
	45.0º	-87.25	62.99	0.52
	67.6º	-220.20*	47.25	0.00
45.0º	0.0º	149.94	58.40	0.08
	22.5º	87.25	62.99	0.52
	67.6º	-132.95	56.78	0.12
67.6º	0.0º	282.88*	40.92	0.00
	22.5º	220.20*	47.25	0.00
	45.0º	132.95	56.78	0.12

I: Comparison group I
J: Comparison group J

4. Conclusions

The rind thickness showed an average of 1.46±0.27cm (P<0.01). Based on visual observation, the rind thickness was directly proportionate to watermelon's physical size.

However, the rind thickness has a random distribution at different positions of the rind (*P*>0.01). The rind thickness showed a positive Pearson correlation between weight, minor circumference, major circumference, minor diameter and major diameter. Therefore, the increase of physical values will in turn increase the rind thickness. On the other hand, the rupture force demonstrated that the direction of penetration angle significantly affects the rupture force value obtained (*P*<0.01), and it was directly proportional to the increase of penetration angles which ranged between 21.48N to 24.25N. This is due to the increase in the penetration angle causing the contact surface area between the punch and the outer skin surface to also increase and indirectly increase the rapture force. Hence, it is very important to take into consideration the watermelon physical size in order to determine the thickness of the rind before conducting the peeling process. In addition, penetration angle factors also should be considered to ensure that the process runs at an optimum level.

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Conflict of Interest: The author declares no conflict of interest.

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