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# EFFECTS OF THE PHYSICAL DIMENSIONS ON FORCES TO BREAK MELON SEEDS AND COTYLEDONS

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## ABSTRACT

The mechanical shelling of melon seeds in experimental impeller-type machines resulted in high percentages of broken seeds and cotyledons. It is difficult to predict the orientations of the seeds during impact with the cylindrical ring. The physical dimensions of melon seeds were measured and compressed between parallel plates in a rig to determine the forces when broken. The average forces found to break the seeds were 12.54, 18.92 and 19.58 x $10^{-3}$N when the seeds were loaded breadthwise, lengthwise with tip up and lengthwise with tip down respectively. The average forces found to break the cotyledons were 8.58, 13.26 and 10.26 x $10^{-3}$N respectively.

The statistical analyses showed that the length, width and thickness of the seeds and cotyledons had significant linear effects on the forces. The seeds and cotyledons loaded or impacting the ring lengthwise were found to be more likely to break compared to the breadthwise orientation. These findings show that melon seeds that are loaded or impacted the ring breadthwise are less likely to be broken, reducing the percentage of broken seeds and cotyledons during the shelling process.

**KEYWORDS**: Break force, melon seeds, cotyledon

## INTRODUCTION

Melon seeds are small and flat containing white cotyledons in thin walled shells having a thick ring around the edges with a tip at the top. The manual shelling to extract the cotyledon is tedious partly due to the size and the thick ring around the edges. The mechanical method resulted in high percentages of broken seeds and cotyledons (Fayoriju and Okokon, 1974; Odigboh, 1979; Egbuta and Uyah, 2003). Isiaka et al.,(2006) in their investigation on some physical properties of 'Bara' variety of melon seeds found that the average length, width, thickness and equivalent diameter for unshelled seeds were 15.39 mm, 9.48 mm, 1.44 mm and 5.94 mm while that of the kernels(cotyledons) were 12.94 mm, 6.64 mm, 1.38 mm and 4.91 mm respectively. The results showed a high variation in the principal dimensions. The sphericity and roundness were 0.39 and 0.52 for unshelled seeds and the corresponding values of 0.38 and 0.49 for the kernels.

In the mechanical shelling of melon seeds, the seeds move between the vanes on the rotating impeller. The seeds leave the impeller and impact on a stationary ring, thereby shelling the seeds. Odigboh (1979) used spinning discs, 450 mm diameter with vanes in various configurations. The seeds were confined to move in the 3.5 mm space between the discs and the cover. He suggested that the preferred orientation of melon seeds is flat-down and since the average thickness of the seeds is 2.5 mm, the seeds tend to move in a single-seed layer within the available space. Egbuta and Uya (2003) used impellers; 230 and 270 mm diameter with vanes. The vanes were spaced to allow free movement of seeds but confirmed to move in the 10 mm space between the impeller and the cover. It is difficult to predict accurately the path of the seeds within the vanes and the orientations of the seeds during impact as their motion is random as a result of multiple impacts. It is likely that the seeds impact the ring at either breadthwise or lengthwise. It is envisaged that the modes of impact of the seeds on the ring could affect the effectiveness and breakage of seeds during shelling.

The objective of the paper is therefore a simulation of the impact forces interaction in the melon seeds shelling process. Statistical analysis showing the relationships between the forces and the physical dimensions of melon seeds is presented.

## MATERIALS AND METHOD

Melon seeds bought from the market were sorted to obtain clean whole seeds. One-halve of the sample was shelled manually to obtain the cotyledons. The moisture content of the sample during the experiment was determined using the oven method as recommended by ASAE, 1990. From each of the two sub-samples, 20 seeds were randomly selected for the compression test.

### Experimentation.

The length l, width w and thickness t of each seed were measured and then compressed between two parallel plates in a rig until the seed broke by bending. The force required to break the seed was measured with a sensitive spring gauge. In the test, the seeds were placed breadthwise, lengthwise with tip up and lengthwise with the tip down. The tests were also carried out with cotyledons.

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**Statistical analysis**

A polynomial equation was used to fit the experimental data on whole melon seeds and the cotyledons. The relationships between the static breaking forces and the length, width and thickness of whole melon seeds in three loading orientations are:

$$F_{sb} = 3.64 \times 10^{-3} + 6.32 \times 10^{-5} l^{1} + 1.44 w - 6.54 t \quad \text{-----------------------------------------------}(1)$$

$$F_{slu} = 1.75 \times 10^{-2} - 1.09 l + 2.59 w - 23.1 t \text{ --- } (2)$$

$$F_{sld} = -5.89 \times 10^{-3} + 0.79 l + 0.92 w + 2.52 t \text{ ----------}(3)$$

Where: $F_{sb}$, $F_{slu}$ and $F_{sld}$ are forces in N at breadthwise, lengthwise with tip up and lengthwise with tip down orientations respectively; $l$ is the length, w is the width, and t is the thickness of the seeds all in m. The corresponding relationships for cotyledons are:

$$F_{cb} = -0.24 + 35.88 l + 2.27 w - 0.42 t \quad \text{----------------}(4)$$

$$F_{clu} = 0.12 + 0.46 l - 27.29 w - 2.15 t \text{--------------------------}(5)$$

$$F_{cld} = 2.07 \times 10^{2} - 0.93 l + 0.92 w - 3.51 t \text{------------------}(6)$$

Where: $F_{cb}$, $F_{clu}$ and $F_{clu}$ are forces in N at breadthwise, lengthwise with tip up and lengthwise with tip down orientations respectively; $l$ is the length, w is the width, and t is the thickness of the cotyledons all in m.

Three statistical parameters below were chosen to evaluate the comparative results of the experimental and the predicted values (Ramesh, 2000).

(a) Root mean square difference (RMSD)

$$\text{RMSD} = \sqrt{\frac{\sum (F_{\exp} - F_{pred})^2}{N}} \text{ ------------------}(7)$$

(b) Standard deviation of difference ($S_D$)

$$S_D = \sqrt{\frac{\sum (F_{\exp} - F_{pred})^2 - \frac{\left[\sum (F_{\exp} - F_{pred})^2\right]}{N}}{N}} \text{ ----}(8)$$

(c) The average percentage error (*E*)

$$E = \frac{100}{N} \sum \frac{|F_{\exp} - F_{pred}|}{F_{\exp}} \text{ ------------}(9)$$

where $F_{exp}$ is the experimental force in N, $F_{pred}$ is the predicted force in N and *N* is the number of data points.

## RESULTS AND DISCUSSION

The moisture content of the melon seeds at the time of experiment was 8.2 % w. b. A summary of the length, width and thickness of the samples of whole melon seeds and cotyledons is shown in Table 1.

In the breadthwise loading, the average force found to break the seeds is 12.54 x $10^{-3}$N (Table 2). The analysis (equ. (1)) showed that the breaking force is inversely related to the length. The force decreases with increase in length. The force is linearly related ($P \leq 0.05$) to the width and the term is positive, showing that the values of the breaking force increases with the width. The force is linearly related to the thickness. The linear effect ($P \leq 0.05$) is negative and significant, and decreases the force with increase in the thickness. The resulting effect is a decrease in breaking force with large seeds. Hence large sized seeds when subjected to forces higher than the average breaking force are likely to break when loaded or during impact breadthwise.

In the lengthwise loading with tip up, the average force found to break the seeds is 18.92 x $10^{-3}$N (Table 3). The force as shown in equ. (2) is linearly related to the length. The linear effect ($P \leq 0.05$) is negative which means that the breaking force is reduced with increase in the length. The force is also linearly related to the width and the linear effect is positive and increases the breaking force with increase in the width. The force is linearly related to the thickness. The linear effect ($P \leq 0.05$) is negative and significant which reduces the breaking force with increase in thickness. As a result, there is a decrease in the breaking force with increase in the physical dimensions. Hence large seeds, when subjected to forces higher than the average breaking force are likely to break when loaded lengthwise with the tip up or impacting with the tip of the seed.

In the lengthwise loading with the tip down, the average force found to break melon seeds is 19.58 x$10^{-3}$N (Table 4). The force is linearly related ($P \leq 0.05$) to the length, width and thickness (equ. (3)). The linear effects ($P \leq 0.05$) are all positive, which means an increase in breaking force with increase in the physical dimensions. Hence smaller sized seeds when subjected to forces higher than the average breaking force are likely to break when loaded lengthwise with the tip down or impacting with the bottom of the seed.

These findings show that when seeds are loaded or impacted breadthwise and lengthwise with tip up, are more likely to break and these constitute a high percentage of broken seeds. Therefore, the variations in the physical dimensions of melon seeds and the orientations affect the breakage of seeds during loading or impact (Isiaka et al., 2006).

During the breadthwise loading of cotyledons, the force found to break cotyledons is 8.58 x$10^{-3}$ N (Table 5). The analysis shows (equ. (4)) that the force is linearly related to the length. The effect ($P \leq 0.05$) is positive and significant, and increases the breaking force with increase in length. The force is linearly related to the width and is positive and increases the breaking force with the increase in the width. The force is linearly related to the thickness, but the term is negative, decreasing the breaking force with increase in the thickness. As a result, the breaking force increases with increase in the physical dimensions. Hence small sized cotyledons when subjected to forces greater than the average breaking force are more likely to break when loaded or during impact breadthwise.

In lengthwise loading with tip up, the average force found to break the cotyledons is 13.26 x$10^{-3}$N (Table 6). The force (equ. (5)) is linearly related to the length and the term is positive, which means an increase in the breaking force with increase in length. The force is linearly related to the width but the term is negative and significant ($P \le 0.05$) This results in a decrease in breaking force with increase in the width. The force is linearly related to the thickness and the term is negative, which decreases the breaking force with increase in thickness. As a result, the breaking force decreases with increase in the physical dimensions. Hence large sized cotyledons when subjected to forces greater than the average breaking force are more likely to break when loaded or during impact lengthwise with tip up.

In lengthwise loading with tip down, the average force found to break the cotyledons is 10.26 x $10^{-3}N$ (Table 7). The force (equ. (6)) is linearly related to the length. The linear effect ($P \le 0.05$). is negative which means a decrease in breaking force with increase in length. The force is linearly related to the width and the term is positive which increases the breaking force with increase in width. The force is linearly related to the thickness and the term is negative, which decreases the breaking force with increase in the thickness. As a result, the breaking force decreases with increase in the physical dimensions. Hence large sized cotyledons when subjected to forces greater than the average breaking force are more likely to break when loaded lengthwise with tip down or impact with the bottom. The findings therefore suggest that large cotyledons are more likely to break. It is assumed that some broken cotyledons are due to the multiple impacts in the machine during the shelling process. These results are comparable with the findings by Okokon et al. (2005) in their study on the shelling characteristics of melon seeds in a rotating impeller with the seeds impacting on a fixed ring. A study of shelled but broken seeds (broken cotyledons) revealed that seeds at 6 3 percent m. c (wet basis), had 54.4% of the cotyledons broken along the xx axis (Fig. 1), implying impact of the seeds with the ring lengthwise, while 27.7% were broken along yy axis implying impact breadthwise. The percentage of seeds that impacted the ring lengthwise was found to be twice that of breadthwise. Seeds at 20.4 percent m. c (wet basis), had 36.8% of the cotyledons broken along the xx axis, and 9.1% were broken along yy axis. Since it is difficult to predict accurately the path of the seeds within the vanes, the findings show that the orientations of the seeds during impact with the ring actually affect the percentage of broken seeds and cotyledons.

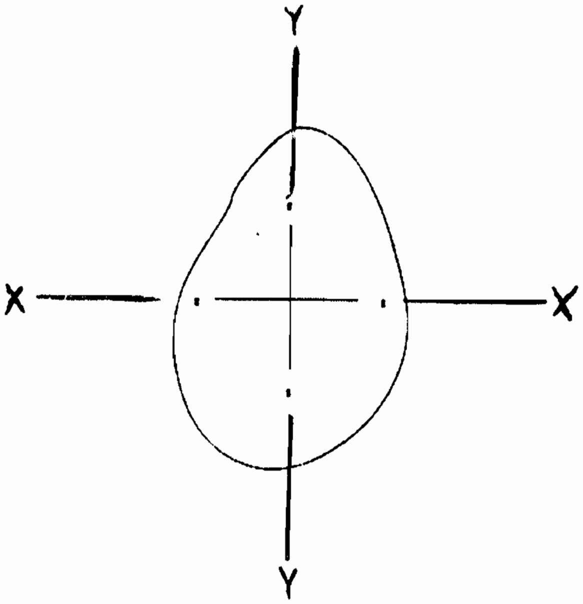

**Fig 1:** Bending exes on melon seed flat side

## CONCLUSION

A simulation of the forces to break melon seeds and cotyledons during impact was studied by compressing them between two parallel plates in three orientations. The average forces found to break whole seeds were 12.54, 18.92 and 19.58 x $10^{-3}$N for breadthwise, lengthwise with tip up and lengthwise with tip down respectively. The average forces found to break cotyledons were 8.58, 13.26 and 10.26 x $10^{-3}$N respectively. The physical dimensions of length, width and thickness of the seeds and cotyledons were found to have linear effects on the breaking forces and some were significant. The statistical analysis show that large sized seeds and cotyledons are more likely to break when loaded or during impact. These findings could aid in the proper design of mechanical melon shelling machines to minimize the percentage of broken cotyledons and seeds. A comparison of the experimental and predicted values as shown in Tables 8 and 9 define the degree of fit of the equations Therefore the equations showing the relationships between the breaking forces and the physical dimension were found adequate.

**Table 1**: Summary of the physical dimensions of whole melon seeds and cotyledons

| **Physical dimension** | **Whole seeds** | | | **Cotyledon** | | |
|---|---|---|---|---|---|---|
| | Range | Mean | SD | Range | Mean | SD |
| Length (mm) | 12.25 – 16.15 | 13.75 | 0.92 | 10.65 – 13.9 | 12.93 | 0.58 |
| Width (mm) | 7.19 – 9.9 | 8.69 | 0.71 | 6.5 – 8.9 | 8.11 | 0.43 |
| Thickness (mm) | 1.3 – 1.9 | 1.75 | 0.21 | 1.21 – 1.77 | 1.65 | 0.28 |

**Table 2:** The physical dimensions of whole melon seed and breaking forces at breadthwise loading

| *Length* *($l$ x $10^{-3}$), m* | *Width* *($w$ x $10^{-3}$), m* | *Thickness* *($t$ x $10^{3}$), m* | *Force* *($F$ x $10^{3}$), N* |
|---|---|---|---|
| 15.00 | 10.00 | 1.76 | 13.8 |
| 14.40 | 9.94 | 1.76 | 13.7 |
| 15.26 | 8.71 | 1.62 | 12.5 |
| 15.96 | 9.28 | 1.34 | 13.7 |
| 15.68 | 9.32 | 1.50 | 11.3 |
| 15.45 | 9.31 | 1.53 | 12.5 |
| 15.70 | 9.12 | 1.67 | 13.8 |
| 15.58 | 9.29 | 1.99 | 11.3 |
| 15.87 | 9.60 | 1.96 | 11.2 |
| 14.85 | 9.54 | 1.90 | 10.5 |
| 16.23 | 9.53 | 1.63 | 12.6 |
| 14.76 | 9.55 | 2.00 | 13.7 |
| 15.86 | 9.52 | 1.58 | 13.7 |
| 15.21 | 9.06 | 1.59 | 11.3 |
| 15.33 | 9.44 | 1.53 | 13.8 |
| 14.93 | 8.79 | 1.94 | 11.3 |
| 15.33 | 9.54 | 1.95 | 12.4 |
| 15.84 | 9.63 | 1.95 | 13.6 |
| 14.95 | 9.79 | 1.73 | 12.6 |
| 17.01 | 9.13 | 1.60 | 11.4 |
| Mean 15.46 | 9.40 | 1.73 | 12.54 |

**Table 3:** The physical dimensions of whole melon seed and breaking forces at lengthwise loading with tip up

| *Length* *($l$ x $10^{-3}$), m* | *Width* *($w$ x $10^{-3}$), m* | *Thickness* *($t$ x $10^{3}$), m* | *Force* *($F$ x $10^{3}$), N* |
|---|---|---|---|
| 15.45 | 9.88 | 1.73 | 18.8 |
| 13.53 | 9.17 | 1.58 | 23.7 |
| 14.06 | 9.12 | 1.54 | 21.2 |
| 15.43 | 9.29 | 1.80 | 22.5 |
| 14.88 | 8.72 | 1.87 | 22.7 |
| 14.86 | 9.70 | 1.64 | 22.4 |
| 14.76 | 8.82 | 1.89 | 20.1 |
| 14.91 | 8.64 | 1.69 | 18.7 |
| 15.39 | 9.48 | 1.72 | 18.8 |
| 15.45 | 9.50 | 1.54 | 21.3 |
| 15.86 | 8.64 | 1.98 | 20.0 |
| 15.05 | 8.98 | 1.66 | 22.4 |
| 15.13 | 9.56 | 1.67 | 21.2 |
| 14.57 | 8.67 | 1.77 | 16.3 |
| 15.29 | 9.03 | 1.71 | 18.7 |
| 14.86 | 9.47 | 1.51 | 15.1 |
| 14.06 | 8.51 | 1.94 | 16.3 |
| 15.60 | 9.16 | 1.95 | 20.1 |
| 15.45 | 8.82 | 1.71 | 15.1 |
| 14.53 | 9.60 | 1.97 | 16.3 |
| Mean 14.96 | 9.14 | 1.74 | 18.92 |

**Table 4**: The physical dimensions of whole melon seed and breaking forces at lengthwise loading with tip down

| | *Length* *($l \times 10^{-3}$), m* | *Width* *($w \times 10^{-3}$), m* | *Thickness* *($t \times 10^{-3}$), m* | *Force* *($F \times 10^{-3}$), N* |
|---|---|---|---|---|
| | 14.29 | 9.03 | 1.27 | 18.8 |
| | 15.98 | 8.98 | 2.01 | 21.2 |
| | 14.60 | 9.31 | 2.25 | 19.9 |
| | 15.45 | 10.01 | 1.98 | 21.2 |
| | 15.09 | 9.91 | 1.51 | 17.6 |
| | 15.96 | 9.59 | 1.69 | 23.7 |
| | 16.79 | 9.07 | 1.70 | 18.8 |
| | 14.12 | 8.79 | 1.58 | 16.3 |
| | 15.02 | 9.26 | 1.68 | 20.0 |
| | 15.17 | 9.92 | 1.69 | 18.8 |
| | 14.57 | 9.16 | 1.55 | 15.1 |
| | 15.25 | 9.25 | 1.67 | 17.6 |
| | 15.81 | 8.65 | 2.37 | 17.4 |
| | 15.21 | 9.14 | 2.43 | 21.3 |
| | 15.72 | 10.46 | 1.92 | 25.1 |
| | 15.46 | 9.78 | 1.59 | 18.7 |
| | 16.84 | 10.36 | 1.65 | 22.4 |
| | 14.79 | 10.04 | 1.51 | 18.9 |
| | 15.76 | 9.41 | 1.79 | 18.8 |
| | 15.24 | 9.09 | 1.89 | 19.9 |
| **Mean** | 15.34 | 9.46 | 1.79 | 19.58 |

**Table 5**: The physical dimensions of cotyledons and breaking forces at breadthwise loading.

| | *Length* *($l \times 10^{-3}$), m* | *Width* *($w \times 10^{-3}$), m* | *Thickness* *($t \times 10^{-3}$), m* | *Force* *($F \times 10^{-3}$), N* |
|---|---|---|---|---|
| | 13.56 | 7.98 | 1.49 | 10.1 |
| | 12.61 | 7.85 | 1.98 | 8.7 |
| | 13.77 | 8.41 | 1.93 | 6.3 |
| | 12.18 | 8.54 | 1.28 | 7.6 |
| | 12. 21 | 8.45 | 1.38 | 10.0 |
| | 12.08 | 8.50 | 1.36 | 7.5 |
| | 12.50 | 8.23 | 1.50 | 8.8 |
| | 12.78 | 7.86 | 1.72 | 11.2 |
| | 11.83 | 8.04 | 1.35 | 8.8 |
| | 12.20 | 7.87 | 1.96 | 7.4 |
| | 13.11 | 7.77 | 1.67 | 7.4 |
| | 12.78 | 8.92 | 1.58 | 11.3 |
| | 13.10 | 8.03 | 1.39 | 8.7 |
| | 12.27 | 7.99 | 1.93 | 7.6 |
| | 12.53 | 8.05 | 1.51 | 7.5 |
| | 12.76 | 7.65 | 1.72 | 6.2 |
| | 13.04 | 7.81 | 1.58 | 6.3 |
| | 12.47 | 8.13 | 1.53 | 8.8 |
| | 12.78 | 8.79 | 1.98 | 11.3 |
| | 12.10 | 8.29 | 1.38 | 10.1 |
| **Mean** | **12.63** | **8.16** | **1.61** | **8.58** |

**Table 6: The physical dimensions of cotyledons and breaking forces at lengthwise loading with tip up**

| *Length* *($l \times 10^{-3}$), m* | *Width* *($w \times 10^{-3}$), m* | *Thickness* *($t \times 10^{-3}$), m* | *Force* *($F \times 10^{-3}$), N* |
|---|---|---|---|
| 12.52 | 8.02 | 1.91 | 13.5 |
| 12.76 | 8.45 | 1.00 | 15.1 |
| 13.45 | 8.42 | 1.60 | 13.7 |
| 13.21 | 8.48 | 1.94 | 12.6 |
| 12.89 | 7.55 | 1.60 | 15.0 |
| 12.55 | 8.48 | 1.71 | 11.2 |
| 13.07 | 7.54 | 1.37 | 12.6 |
| 12.90 | 7.74 | 1.48 | 13.7 |
| 12.29 | 8.05 | 1.54 | 12.1 |
| 13.61 | 7 14 | 1 50 | 15.1 |

| | | | |
|---|---|---|---|
| 12.39 | 7.64 | 1.96 | 11.3 |
| 12.36 | 8.46 | 1.91 | 12.5 |
| 13.41 | 7.38 | 1.62 | 13.8 |
| 12.45 | 7.76 | 1.74 | 11.3 |
| 13.23 | 7.87 | 1.43 | 13.8 |
| 12.81 | 7.62 | 1.97 | 12.6 |
| 12.30 | 7.91 | 1.25 | 15.1 |
| 13.69 | 7.90 | 1.27 | 12.6 |
| 13.85 | 8.47 | 1.96 | 13.8 |
| 12.73 | 8.20 | 1.17 | 13.8 |
| Mean 12.92 | 7.95 | 1.60 | 13.26 |

**Table 7**: The physical dimensions of cotyledons and breaking forces at lengthwise loading with tip down.

| *Length* ($l \times 10^{-3}$), *m* | *Width* ($w \times 10^{-3}$), *m* | *Thickness* ($t \times 10^{-3}$), *m* | *Force* ($F \times 10^{-3}$), *N* |
|---|---|---|---|
| 12.89 | 8.25 | 1.86 | 12.4 |
| 12.89 | 8.20 | 1.85 | 12.6 |
| 13.63 | 7.21 | 1.65 | 8.8 |
| 13.14 | 8.06 | 1.54 | 11.3 |
| 12.67 | 8.01 | 1.26 | 10.0 |
| 12.27 | 8.57 | 1.86 | 11.2 |
| 13.29 | 7.53 | 1.99 | 6.3 |
| 12.89 | 7.07 | 1.93 | 5.1 |
| 13.28 | 8.30 | 1.91 | 12.2 |
| 13.34 | 7.50 | 1.52 | 8.7 |
| 12.65 | 7.63 | 1.63 | 11.3 |
| 12.38 | 7.25 | 1.89 | 8.7 |
| 12.81 | 7.05 | 1.81 | 10.1 |
| 12.21 | 8.99 | 1.55 | 12.6 |
| 12.80 | 6.54 | 1.50 | 11.3 |
| 13.34 | 7.63 | 1.28 | 12.6 |
| 13.89 | 7.74 | 1.54 | 10.0 |
| 13.36 | 8.15 | 1.90 | 8.6 |
| 13.48 | 8.45 | 1.56 | 10.1 |
| 12.64 | 8.03 | 1.26 | 11.3 |
| Mean 12.99 | 7.81 | 1.66 | 10.26 |

**Table 8**: Statistical analysis of the comparison of experimental and predicted forces for melon seeds

| Orientation | RMSD | $S_D$ | E (%) |
|---|---|---|---|
| Breadthwise | $0.9 \times 10^{-3}$ | $0.9 \times 10^{-3}$ | 6.5 |
| Lengthwise with tip up | $1.61 \times 10^{-3}$ | $1.62 \times 10^{-3}$ | 7.5 |
| Lengthwise with tip down | $1.84 \times 10^{-3}$ | $1.84 \times 10^{-3}$ | 9.8 |

**Table 9**: Statistical analysis of the comparison of experimental and predicted forces for cotyledons

| Orientation | RMSD | $S_D$ | E (%) |
|---|---|---|---|
| Breadthwise | $0.9 \times 10^{-3}$ | $0.9 \times 10^{-3}$ | 9.9 |
| Lengthwise with tip up | $0.95 \times 10^{-3}$ | $0.94 \times 10^{-3}$ | 5.7 |
| Lengthwise with tip down | $1.0 \times 10^{-3}$ | $1.0 \times 10^{-3}$ | 9.0 |

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