OnLine Journal of Biological Sciences 1 (10): 925-928, 2001

Dimensional Analysis of Mechanical Behaviour of Some Onion Varieties

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Abstract: The physical and mechanical behaviour of onion differs for each variety. Especially for proper handling and storage of the onion is quite important for preventing the quality loss and plant damage. In this research the dimensional analysis and buckingham Pi Theorem was applied to predict crushing forces of Banko and Yalova 12 onion varieties. Dimensionless pi terms were developed using measured vertical forces, deformation, diameter of the onion, failure strain energy, and modulus of elasticity of onions. The crushing force were predicted with linear correlation value of 0.898.

Key words: Onion, dimensional analysis, mechanical properties

Introduction

Understanding the physical and mechanical properties of onions is important for handling the onion and increasing the shelf life. By using the mechanical properties, one can estimate the strength and conditions of the onion.

Maw *et al.* (1996) were studied on Grane-Grono type sweet onion. For understanding of the some problems they had during storage, they examined the mean -mass, surface area, volume, density and the crushing load and puncture force of the sweet onion.

There are many studies on fruit and vegetables' poisson's ratio and elasticity modulus (Kang *et al.*, 1995). Knowledge of elastic modulus allows comparison of relative strengths of various material to be made.

The dimensional analysis was applied by Srivastava *et al.* (1990) for prediction bruise diameter of the three apple varieties (Ida Red, Golden Delicious and Macintosh) under the static compressive force. They found the relationship using regression analysis ($r^2 = 0,757$)

$$\left(\frac{d}{D}\right) = 0.457\left(\frac{F}{\sigma_{yc}D^2}\right)^{0.227}\cdot\left(\frac{FD}{e_c}\right)^{0.297}\cdot\left(\frac{F}{E_cD^2}\right)^{0.188}$$

where;
d.....Average bruise diameter.........L
D...Average apple diameter...........L
σ_{yc} .Yield strength of apple flesh...FL^{-2}
Ec..Elastic modulus of apple flesh.Ec^{-2}
e_c..Elastic modulus of apple...........e_c^{-2}
F...Applied compressive force.......F

Materials and Methods

The data used in this research were gathered from the previous research from Cakir *et al.* (2000). As it was explained in that research; the crushing force, failure strain energy and modulus elasticity of two onion varieties: Banko (B) and Yalova 12 (Y) were determined. The data were given in Tables 1 and 2.

The pertinent variables for crushing (c) onion for both radial (R) and axial (E) were considered. Dimensional analysis and the Buckingham Pi Theorem (Murphy, 1950; Young, 1992) were used to formulate the expected pi terms for crushing the onions on a rigid surface.

If we look at the relations among the variables for constructing the pertinent variables, we can see that the diameter of onion, failure strain energy and modulus of elasticity of onion can be

Table 1: The mechanical behaviours of Yalova 12 and Banko right after harvest

File Name	Diameter (m)	Length (m)	max. LOAD kn	Max. Stress kN/m^2	Failure strain energy kNm	E=Modulus of elasticity kN/m^2
Y112RC	0.083	0.0651	1.00	184.65	0.001193975	4583
Y96RC	0.080	0.0695	1.36	268.93	0.001246557	6768
Y125RC	0.102	0.0774	1.09	131.50	0.001798762	3557
Y117RC	0.084	0.0873	0.94	169.02	0.000732218	9337
Y94RC	0.068	0.0734	0.94	254.11	0.001041233	8414
Y102EC	0.068	0.0765	0.60	146.40	0.000675517	5620
Y120EC	0.080	0.0731	1.33	290.45	0.001731655	7874
Y111EC	0.076	0.0660	0.85	215.14	0.001591574	6785
Y108EC	0.817	0.0738	1.36	286.58	0.000735358	6566
Y95EC	0.078	0.0710	0.80	183.19	0.000714364	5880
B260RC	0.049	0.0657	0.17	88.030	0.0000604296	6919
B284RC	0.050	0.0500	0.62	307.73	0.000442529	10745
B301RC	0.047	0.0503	0.60	335.86	0.000475393	11230
B283RC	0.053	0.0653	0.74	336.60	0.000668257	11725
B282RC	0.051	0.0485	0.62	302.05	0.00059635	8204
B307EC	0.046	0.4720	0.33	188.39	0.00028086	6431
B275EC	0.049	0.4880	0.60	322.09	0.000590464	-
B269EC	0.085	0.0661	0.21	85.100	0.000144796	4750
B298EC	0.051	0.0512	0.43	207.25	0.000306563	5079

Table 2: The mechanical behaviours of Yalova 12 and Banko right after harvest

File Name	Diameter (m)	Length m	Max. LOAD kn	Max. stress kN/m^2	Failure strain energy kNm	E=Modulus of elasticity kN/m^2
Y130C2	0.0637	0.073	0.69	215.92	0.002713446	1277
Y103RC2	0.0600	0.0589	0.60	212.27	0.002578951	1522
Y221RC2	0.0624	0.0667	0.69	225.01	0.002526075	1743
Y137RC2	0.0664	0.0621	0.72	207.17	0.003239007	1180
Y144RC2	0.0534	0.0603	0.52	232.18	0.001352407	1865
Y148EC2	0.0680	0.0718	0.49	134.18	0.003016281	1065
Y189EC2	0.0444	0.0522	0.30	194.55	0.000992478	1048
Y220EC2	0.0638	0.0620	0.76	237.26	0.002012227	1347
Y128EC2	0.0695	0.0727	0.49	128.84	0.002509496	855
Y154EC2	0.0685	0.0616	0.67	181.96	0.001274221	1548
B334RC2	0.0542	0.0484	0.36	155.95	0.000995617	1208
B229RC2	0.0563	0.0521	0.39	156.32	0.001555474	1063
B343RC2	0.0503	0.0575	0.62	310.88	0.001773452	2294
B309RC2	0.0483	0.0560	0.41	225.20	0.001674469	1533
B268RC2	0.0574	0.0689	0.79	304.42	0.001796113	2817
B367EC2	0.0540	0.0523	0.47	205.71	0.001636897	1462
B271EC2	0.0473	0.0512	0.53	301.52	0.001839767	1426
B365EC2	0.0496	0.0528	0.39	201.41	0.001150909	1292
B280EC2	0.0538	0.0640	0.47	207.24	0.002219218	996
B326EC2	0.0550	0.0546	0.75	314.30	0.002161437	813

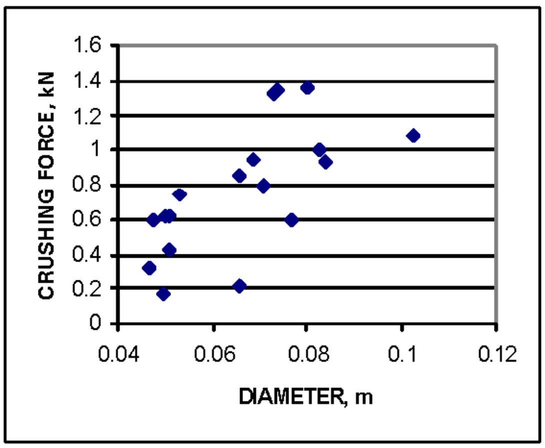

Fig. 1: Crushing force as influenced by the diameter of onion right after harvest

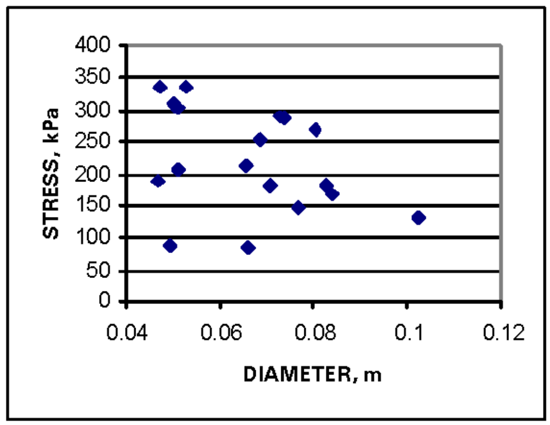

Fig. 2: Crushing stress as influenced by the diameter of onion right after harvest

used for reflecting the behaviour of onion. Figs. 1, 2 and 3 show that the crushing force and failure strain energy increases with the diameter of onion. On the other hand, the crushing stress does not change with the size of the onion. And from the tables 1 and 2, it is obvious that the modulus of elasticity of onion changes with the storage time. So, pertinent variables were selected as: crushing force, diameter of onion, failure strain energy and modulus of elasticity of onion.

Dimensional analysis: The chosen pertinent variables and their basic dimensions for crushing the onions on a rigid surface, were:

$F = f(D, E, e_c)$
where
F...Crushing force of onion (kN); (F)
D...Diameter of onion (m); ....(L)
E...Modulus of elasticity of onion (kPa); (FL-2)
e_c...Failure strain energy (kNm); (FL)
The function can be written as,

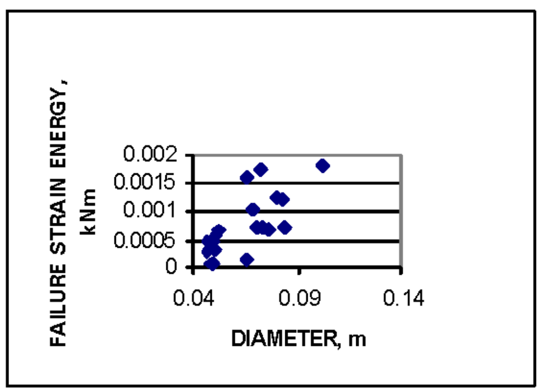

Fig. 3: Failure strain energy as influenced by the Diameter of onion right after harvest

$H(F,D,E,e_c) = 0$

Table 3: Linear regression results of π_1 and π_2 for crushing onions on a rigid surface

			Regression statistics		
Multiple R			0.947717		
R Square			0.898168		
Adjusted R Square			0.895339		
Standard Error			0.019368		
Observations			38		
	ANOVA				
	df	SS	MS	F	Significance F
Regression	1	0.119105	0.119105	317.5223	1.93E-19
Residual	36	0.013504	0.000375		
Total	37	0.132609			
	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	0.01958	0.004464	4.386563	9.62E-05	0.010527
X Variable 1	13.90241	0.780195	17.81916	1.93E-19	12.32011

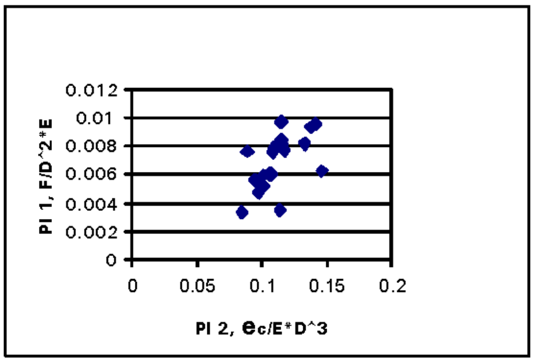

Fig. 4: π_1 versus π_2 for crushing onions on a rigid surface

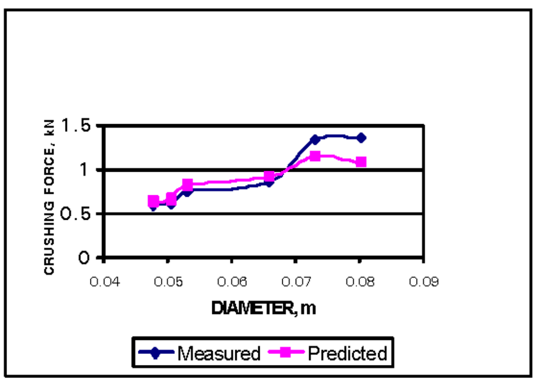

Fig. 5: Measured versus predicted crushing force of onion

therefore the final equation which is the dimensionless is

$$F^0 D^0 E^0 e_c^0 = M^0 L^0 T^0$$

Using the Buckingham Pi Theorem, the Pi terms were formed as follows;

$$\pi_1 = \frac{F}{D^2E}$$

$$\pi_2 = \frac{e_c}{D^2E}$$

The function can be written as

$$\frac{F}{D^2E} = f\left(\frac{e_c}{D^3E}\right)$$

Results and Conclusion

The relation between calculated pi values were given in Fig. 4. The relation can be described almost linear between π_1 and π_2. The linear regression was applied to the Pi terms. embed Excel. Chart.8

The results of regression analysis were given in Table 3. The coefficient of determination (R^2) was found to be 0.898 for crushing the onion on a rigid surface. By using the regression equation from (Table 3), an empirical equation for crushing the onions on a rigid surface can be written in the form of:

$$\pi_1 = a + b\pi_2$$

with substituting the Pi terms in this equation, the empirical equation becomes

$$\pi_1 = 0.0196 + 13.9\pi_2$$

And the crushing force can be predicted as follows;

$$F = 0.0196\, D^2E + 13.9\, \frac{e_c}{D}$$

The predicted crushing force of onion is in good relation with measured values. The Fig. 5 shows the very close relation between measured and predicted crushing force of onion. By using the mechanical properties of two onion varieties: Yalova 12 and Banko, the crushing force of the onion were predicted with developed dimensionless pi terms. With the developed prediction equation, one can predict the crushing force by using the diameter, failure strain energy and the modulus of elasticity of the onion. The dimensional analysis has not been used for onion so far. So the prediction equation gives better r^2 regression result comparing with the previously prediction model of apple bruise diameter by Srivastava and his friends. The use of dimensional analysis reduces the number of variables and produces a more compact yet general prediction equation. The prediction equation found in this study allows a researcher to study the effect of diameter and the firmness of the onion on the crushing force.

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