Effect of Moisture Content on the Mechanical Properties of Cucumber Fruit

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Abstract:

The knowledge of mechanical properties under compressive force is very important factor in the design and development of harvesting, handling and processing systems of agricultural products. In this study the mechanical properties (failure stress, failure energy, failure strain, maximum compressive stress, maximum relative deformation, rupture energy, rupture stress, and Young modulus) of Nandini cucumber (Cucumis sativus L) fruit were investigated. These properties were evaluated at six moisture levels (75, 78, 82, 86, 89, and 92% wet basis) under quasi-compression loading was carried out by using the Testometric Universal Testing Machine (UTM). The results show that moisture content had significant (P<0.05) effect on all the mechanical properties of the cucumber fruit investigated. The results showed that the failure stress, failure energy, maximum compressive stress, rupture stress, rupture energy, and Young modulus significantly decreased by 51.67, 62.79, 51.7, 51.77, 62.03, and 44.73% respectively with increased in moisture content. The result of this experiment shows that as the moisture content increased from 75 to 92% wb, the value of the failure strain and maximum relative deformation increased by 28.72 and 39.475 respectively. The results of this study will be very useful in the design of the cucumber handling and processing machines.

Keywords: Nandini, cucumber, mechanical properties, compressive force, moisture content.

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[1]1.0 INTRODUCTION

Cucumber (*Cucumis sativus* L.), belongs to the *Cucurbitaceae* family like melon, squash and pumpkins. It is commercially cultivated worldwide as a seasonal vegetable crop [37]. Cucumber cultivation is becoming increasingly popular in Nigeria, due to its nutritional and medicinal values. National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, research centre, had identified *Nandini* cultivar of cucumber as a crop with substantial growth and production potential. It is widely consumed fresh in salads or fermented (pickles) or as a cooked vegetable [1].

Cucumber is widely used for various skin problems including swelling under the eyes and sunburn, as it promotes refreshing, cooling, healing, soothing, and anti itching effect to irritated skin [2]. Several pharmacological activities including the antioxidant, antiwrinkle, antimicrobial, antidiabetic, and hypolipidemic potentials have been reported with this plant. Antihyaluronidase and anti-elastase activities have been proved for its cosmetic potentials [3]. Cucumber fruit contain a high concentration of ascorbic acid [4], whereas pulp and peel extracts contain lactic acid (~7–8% w/w), which showed antioxidant activity [1]. The gibberellin hormone was also found in cucumber seeds [5]. Cucumber seed cake contains water (1.13%) protein (72.53%) ash (9.7%), crude fiber (1%) and carbohydrates (8.64%) [6]. Besides this, *cucurbitacins* also exhibited wide ranges of in-vitro or even in-vivo pharmacological effects and in used as purgative, anti-inflammatory and anti-fertility agent [7].

Compression properties of fruits and seeds have been found to be dependent on moisture content and orientation of the materials [8]. The reduction in hull breaking force as the moisture of pumpkin seed increased was reported by [9]; and [10] studied the effects of moisture content on the mechanical properties of *Ahmad Aghaie*`s variety of pistachio and its seed including rupture force, rupture energy in three levels of moisture and observed that rupture force, rupture energy and deformation were significantly affected by moisture. In related development, [11] studied the mechanical properties and effect of force pressure of rice, observed that decreasing moisture, the failure force and energy, apparent elastic modulus and deformation of rice, failure stress, and toughness increases. The required force and energy to failure or break the chickpea in three levels of moisture (7%, 12%, and 16%), two loading directions and three kinds of Iranian chickpea influenced by Quasi-Static forces was studied by [12], and observed that moisture, variety and loading direction have significant effect on required force and energy to break or rupture the grain.

Mechanical properties of cucumber fruit are significantly influenced by the change in moisture content, and the knowledge of these properties is essential in the design of transportation, processing, storage, crushing and milling systems for the cucumber fruit. The physical and mechanical properties are often required to facilitate and improve the design of equipment for handling, transportation, storage, grading machines and other postharvest machines, and also for assessing the product quality [13]; [14]. While [15] reported that adjustment and performance of agricultural product

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processing machine depends on the moisture content of the product.

Currently, there is little or no information on the compressive properties of cucumber fruit necessary for the development of indigenous technologies for the handling and processing of the crop. Therefore, the objective of this study is to determine the effect of moisture content on some compressive strength properties (failure strength, failure strain, failure energy, maximum compressive strength, rupture strength, rupture energy, Young modulus, and relative deformation) of cucumber fruit at different moisture content levels, that will aid in the design and development of handling and processing systems for cucumber fruits.

2.0 MATERIALS AND METHODS

2.1 Sample Collection

The cucumber fruits were collected from the research farm of National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria. The fruits were cleaned manually, and selected based on uniformity, maturity and freedom of bruises, pests and insects attack.

2.2 Moisture Content Determination

The moisture content of the sliced fruit was determined by using the microwave oven-drying method. A sample of the fruit (5 g) was kept in a microwave oven (Samsung microwave oven model CE118 KF), and set at 270 W power level, as recommended by [16]. Moisture loss was measured after every 5 minutes, until stable weight is obtained. The sample was weighed again at the end of the period to determine its final weight. The experiments were replicated 5 times, and the average recorded.

2.3 Moisture Conditioning of the Fruit

The wetting techniques adopted by [17] and [18] were used to vary the moisture content of the fruit. Cut out Samples of the fruit (Figure 1) at desired moisture levels were prepared by adding calculated amounts of distilled water and sealing in separate polyethylene bags and kept in a refrigerator for 48 h to equilibrate the samples. Before starting a test, the required quantity of the sample was taken out of the refrigerator and allowed to warm up to room temperature.

Figure 1: Sliced cucumber fruit (25 mm thickness)

2.4 Determination of the Mechanical Properties of the Cucumber Fruit

The mechanical properties of the cut out section of the fruit were measured at six different moisture contents (75, 78, 82, 86, 89, and 92% wet basis). Compressive test was conducted using a Universal Testing Machine (UTM) (Testometric model, series 500-532), equipped with a 50 N compression load cell and controlled by a micro-processor. A transverse slices of 25 mm thickness cut of the fruit sample was placed in the machine under the flat compression tool (Figure 2), ensuring that the centre of the tool was in alignment with the cut sample, and compressed at the speed rate of 25 mm/min as recommended by [19]. As compression progressed, a force-deformation curve was plotted automatically in relation to the response of each sample of the sample to the compression. Data obtained includes stress at yield, maximum stress, rupture stress, energy at yield, strain at yield, load at break, stress at yield and compressive extension at yield.

According to [20], bioyield point is related to a failure in the microstructure of the material associated with an initial disruption of cellular structure; and the rupture point of the material which correlates to the macroscopic failure (breaking point) in the sample, the failure strength was taken as the stress at which the sample failed in its internal cellular structure. Reference [21] described toughness as the work (energy) required to cause rupture in a product. It is calculated as the maximum energy divided by the sample volume. The compressive strength was the maximum stress which the sample was able to withstand, before it got completely ruptured. Young modulus was taken as the ratio of the stress to the strain up to the failure point [20]; [21]; [22]. For each of the moisture content level, the experiment was replicated five times, and the average recorded.

Figure 2: Cucumber fruit undergoing quasi compressive test using Universal Testing Machine (Testometric model, series 500-532)

2.5 Statistical Analysis

The analysis of variance test (ANOVA) was carried out using the software SPSS 16.0 to examine the effect of moisture content on mechanical properties of the *Nandini* cucumber fruit and followed by Duncan's test ($p < 0.05$). The summary of the readings was plotted in Microsoft Excel 2010, and the coefficients of determination between the properties and the moisture content were determined by using the MS Excel 2010 (Microsoft Corporation Redmond, WA 98052).

3 RESULTS AND DISCUSSION

Table 1 gives the results of analysis of variance (ANOVA) for the effect of moisture on the mechanical properties (failure stress, failure energy, failure strain, maximum compressive stress, maximum relative deformation, rupture stress, rupture energy, and Young modulus) of *Nandini* cultivar of cucumber fruit. As depicted from Table 1, the all the mechanical properties were significantly ($P<0.05$) affected by moisture level of the fruit. While Table 2 presents the regression equations as a function of moisture content with their respective coefficient of determination (R^2) and p-value (p) for all the mechanical properties investigated in this research. The high coefficient of determination values ($R^2 \geq 0.94$) (Table 2) indicates that the plots described the data points reasonably, and there is strong relationship between moisture levels and the mechanical properties tested in the cucumber fruit. The regression results suggest that the mechanical properties of a *Nandini* cucumber sample can be predicted using either the linear or logarithmic equations.

Table 1: Analysis of variance (ANOVA) of effect of moisture level on the mechanical properties of *Nandini* cucumber fruit

Source of variation	Dependent Variable	df	F	Sig.
Moisture content	Failure stress	5	6.4350	0.000633*
	Maximum compressive stress	5	6.5017	0.000593*
	Rupture stress	5	6.4700	0.000611*
	Failure energy	5	8.0584	0.000141*
	Rupture energy	5	7.1094	0.000332*
	Young modulus	5	3.2810	0.021306*
	Failure strain	5	3.7351	0.012135*
	Maximum relative deformation	5	2.7156	0.044124*

* =Significant on the level of 5%, ns= non-significant

Table 2: Regression relationships between mechanical properties and moisture content with their respective coefficient of determination (R^2) and p-value (p).

Parameter	Linear equation	R^2	Logarithmic equation	R^2	p value
Failure stress	y = -0.0136 x + 1.5091	0.9655	y = -1.1263Ln(x) + 5.354	0.9562	0.00015
Failure energy	y = -0.1362 x + 13.976	0.9718	y = -11.357Ln(x) + 52.825	0.9760	0.00014
Failure Strain	y = 1.0079 x - 30.923	0.988	y = 83.989Ln(x) - 318.19	0.9915	0.00268
σ_{Max}	y -0.013 x + 1.462	0.9472	y = -1.0685Ln(x) + 5.1004	0.9341	0.00023
Relative Deformation	y = 0.8673 x - 35.213	0.9928	y = 72.203Ln(x) - 282.1	0.9945	0.00034
Rupture stress	y = -0.0142 x + 1.5589	0.9729	y = -1.1755Ln(x) + 5.5714	0.9635	9.69E-05
Rupture energy	y = -0.1387 x + 14.469	0.9749	y = -11.512Ln(x) + 53.798	0.9710	0.00010
Young modulus	y = -0.036 x + 4.3064	0.9187	y = -2.9835Ln(x) + 14.494	0.9116	0.00067

Evaluation of the effect of moisture on the mechanical properties of Nandini cucumber fruits

3.1 Effect of Moisture Content on Failure Stress

The failure stress showed significant ($p < 0.05$) variation with the moisture content (Table 1). Regression relationship between moisture content and failure stress of the *Nandini* fruit can be expressed mathematically in the regression equations presented in Table 2. Failure stress required to initiate the failure of the cucumber fruit at different moisture content shown in Figure 3, depicts that the stress required initiating the fruit's failure decreased from 0.478 to 0.231 MPa (51.67% decreased) as the moisture content increased from 75% to 92%. The result also shows that failure stress is highly dependent on moisture content of the *Nandini* cucumber fruit. The small failure stress at higher moisture content can be attributed to the fact that the *Nandini* fruit developed soft textural structure at higher moisture content. The result is in consistent with the report for shea nut [23] and faba bean [24].

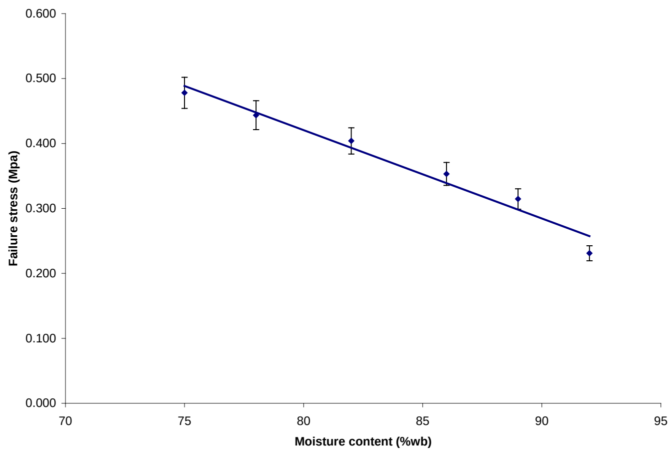

Figure 3**:** Effect of moisture content on the failure stress of cucumber fruit

3.2 Effect of Moisture Content on the Failure energy

The Failure energy of the *Nandini* cucumber fruit was significantly ($P \leq 0.05$) influenced by the moisture content level (Table 1), and it decreased linearly with increased in moisture level (Figure 4). The regression equations for failure energy with variations with the moisture level are presented in Table 2. The effect of moisture content on energy at yield presented in Figure 4, shows that failure energy is significantly ($P \leq 0.05$) dependent on moisture content of the fruit. The energy reduced from 3.854 to 1.434 Nm (62.79% decreased) as the moisture content increase from 75 to 92% wb. The implication of the above result is that the energy needed in compression to initiate failure of the fruit's intercellular structure is significantly dependent on the moisture content of the fruit. Minimum energy would be required when the fruit is processed (milled) at higher moisture levels. A similar observation was reported by [25] on cowpea.

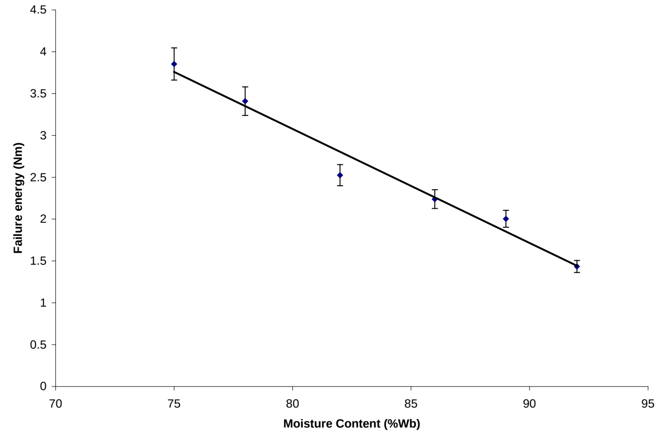

Figure 4: Effect of moisture content on the failure energy of cucumber fruit

3.3 Effect of Moisture Content Failure Strain

The result of the statistical analysis on the effect of moisture on the failure strain was significant ($P < 0.05$). The regression analysis indicating the relationship between moisture content and failure strain can be represented by the regression equations presented in Table 2. The deformation of the fruit increased as the moisture content increased from 75 to 92% wb (Figure 5), increasing from 43.63% to 61.21% (28.72% increased). As the moisture content of fruit increases, the maximum compressive force decreased but its position on force–displacement curve increased so the slope of stress-strain curve decreased for this reason the stress decreased and the strain increased by time passing [26].

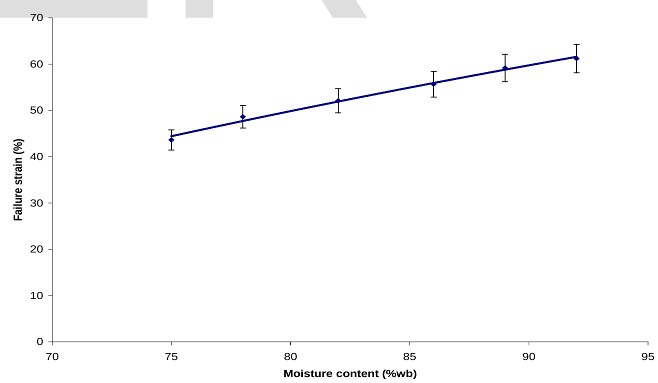

Figure 5: Effect of moisture content on the failure strain of cucumber fruit

3.4 Effect of Moisture Content on the Maximum Compressive Stress

As presented in the ANOVA table (Table 1) moisture had significant ($p < 0.05$) effect on the maximum compressive stress of the cucumber fruit. The maximum compressive stress decreased linearly with the increase in moisture content as represented by Figure 6. The maximum compressive stress reduced from 0.482 to 0.233 MPa (51.7% decreased) as the moisture content increase from 75 to 92% wb. The decrease in maximum compressive stress of the fruit can be attributed to the fruit becoming softer at increased moisture levels, thereby, unable to withstand higher forces. Similar findings were reported for wheat [28] and cumin seed [27]. The mechanical resistance of fruit depends on the cellulosic compounds of the cell wall and composites that bind the cells together [12], and it is highly dependent on the amount of moisture present in the fruit.

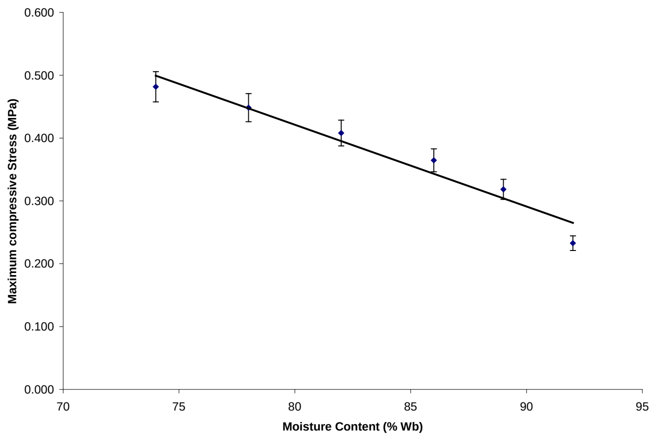

Figure 6: Effect of moisture content on the maximum compressive stress of cucumber fruit

3.5 Effect of Moisture Content on the Maximum Relative Deformation

The ANOVA table (Table 1) shows that the fruit's moisture had significant ($p < 0.05$) effect on the maximum relative deformation of the cucumber fruit. The maximum relative deformation increased linearly with the increase in moisture content as represented by Figure 7. As shown in Figure 5, the deformation of the fruit increased from 29.22% to 44.59% (39.47% increased), as the moisture content increased from 75 to 92% wb. The reason is that increased moisture due to skin softening causes increased deformation, also with moisture reduction, deformation increased firstly and then it decreased [29]. This may be attributed to the softening of the fruit as moisture increases, which results in the higher deformation [30]; and increase in deformation tendency of the fruit skin resulting in increased deformation under pressure [31]. This result is similar to the one achieved by [11] in determining physical and mechanical properties of hazelnut and its seed, who observed increasing deformation with increased in moisture. Reference [32] reported that the cracking force of bambara groundnut decrease from 262 to 100 N with increase in moisture content while deformation increased from 19 to 45 mm with increase in moisture content.

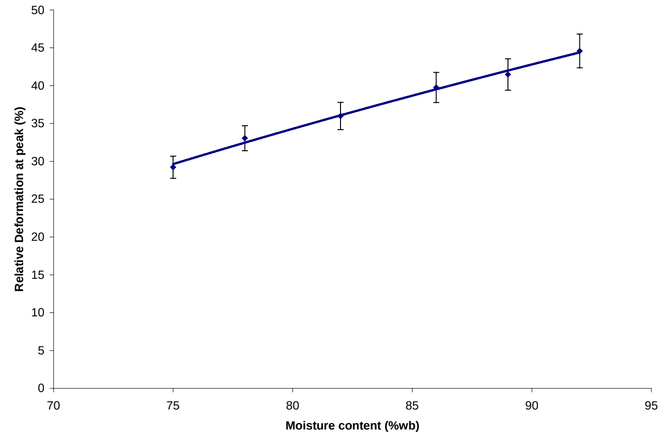

Figure 7: Effect of moisture content on the maximum relative deformation of cucumber fruit

3.6 Effect of Moisture Content on the Rupture Stress

The result of the statistical analysis on the effect of moisture content on rupture stress was found to be significant ($p \leq 0.05$) (Table 1). The regression equations on the effect of moisture content of the fruit on the rupture stress at different moisture content level are shown in Table 2, and the values shows a strong relationship because moisture and the rupture stress. As shown in Figure 8 shows how moisture content affects the rupture stress of the *Nandini* fruit. It could be observed from Figure 8 that as the moisture content increased from 75 to 92 % wb, the rupture stress decreased from 0.481 to 0.323 MPa (51.77% increased). This shows that lesser rupturing force was required to rupture the cucumber fruit at higher moisture content. Increasing the moisture content of the fruit probably damaged the cellular structure of the fruit and consequently rupture occurred at a lower level of compressive force. The result is similar to those reported for various crops such as terbinth [33] and almond nut [34]. In addition, [24] conducted a study on the effects of the moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains and reported that, as the moisture content increased from 9.89% to 25.08%, the rupture force values ranged from 314.17 to 185.10 N.

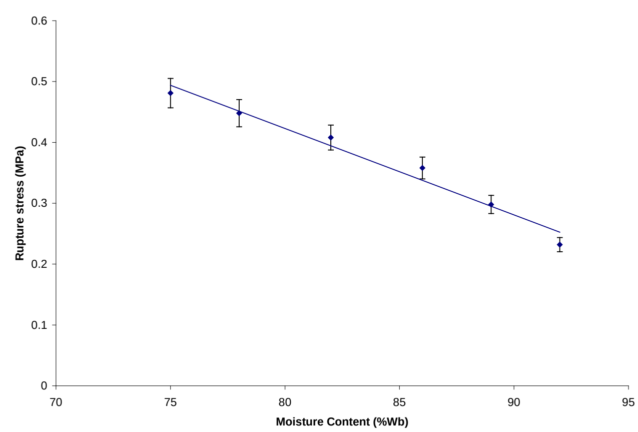

Figure 8: Effect of moisture content on the rupture stress of cucumber fruit

3.7 Effect of Moisture Content on the Rupture Energy

From the ANOVA table, (Table 1) moisture had significant ($p \leq 0.05$) effect on the rupture energy of the cucumber fruit. The results of the rupture energy are presented in Figure 9, and the rupture energy values ranged from 4.014 to 1.524 Nm (62.03% decreased). The result show that the rupture energy (Figure 9) is highly dependent on moisture content for the range of moisture content investigated (75 – 92 % w.b.). The highest rupture energy at the moisture content of 75.00 %, while the lowest was at a moisture content of 92.00 %, therefore, at the lower moisture content levels, the rupture energy was high and vice versa. Regression relationship between moisture content and rupture energy of the *Nandini* fruit can be expressed mathematically in the regression equations presented in Table 2. The result is similar to these reported by [35] for cashew nuts, and [24] for faba bean grains. In addition, [10] observed in determining the effect of moisture on some mechanical properties of three varieties of Pistachio that decreasing moisture, the toughness increases.

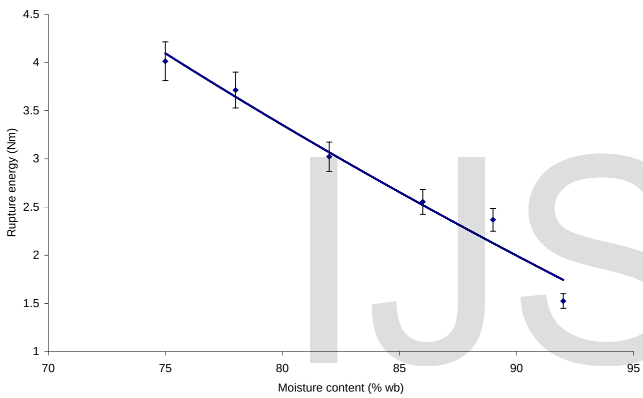

Figure 9: Effect of moisture content on the rupture energy of cucumber fruit

3.8 Effect of Moisture Content on the Young Modulus

The Young modulus decreased significantly ($p < 0.05$) with an increase in the moisture content of the cucumber fruit. Variation of Young modulus of *Nandini* cucumber fruit with moisture, when subjected to compressive loading is presented in Figure 10. According to Figure 10, the Young modulus decreased from 1.623 to 0.897 MPa (44.73% decreased) along with increasing moisture content within the sampling time. The Young modulus of *Nandini* fruit showed a general decreased with increase in moisture content, which may be attributed to the lower resistance offered to rupture by the fruit at the higher moisture content. Similar results were obtained by [36] for carob pod and soybean. Mechanical properties of cucumber are vital factors that aid the design of specific machines of the product during agricultural processes such as planting, harvesting, handling, crushing, and milling.

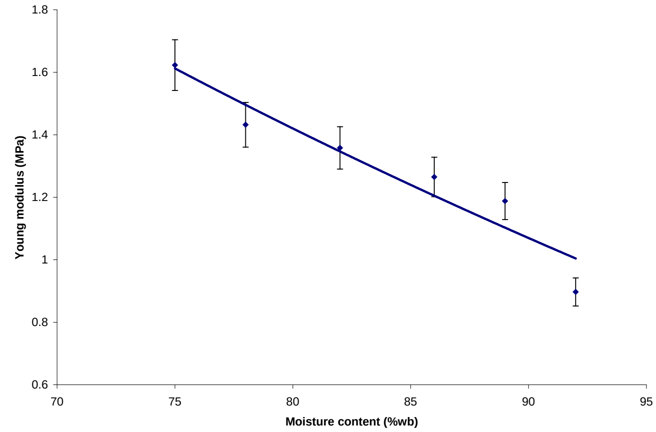

Figure 10: Effect of moisture content on the Young modulus of cucumber fruit

4. CONCLUSION

The study was carried out to find out the effect of moisture content on the mechanical properties of cucumber fruit. ANOVA performed on the sample results showed that moisture content had a significant ($P \leq 0.05$) effect on all mechanical properties investigated. Mechanical properties of cucumber fruit viz., failure stress, failure energy, failure strain, maximum compressive stress, maximum relative deformation, rupture stress, rupture energy and Young modulus, showed a strong linear relationship with the rising moisture level from 75 to 92% wet basis. The fruit Failure stress, failure energy, maximum compressive stress, rupture stress, rupture energy and Young modulus decreased with increased in moisture content, whereas, the failure strain and maximum relative deformation increased linearly with increase in Moisture content. Mechanical properties of cucumber are vital factors that aid the design of specific machines of the product during agricultural processes such as planting, harvesting, handling, crushing and milling. This study provides vital information in the design and development of cucumber fruit handling, transportation and processing structures.

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