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Moisture-Dependent Mechanical and Textural Properties of Intact Cucumber Fruit

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***Abstract*— In this research some mechanical and textural properties of cucumber fruit (cv Nandini) were analyzed for six moisture content levels 72.03, 75, 78, 81, 84, and 87% (W.b). These mechanical parameters (failure force, failure energy, maximum compressive force, rupture force, rupture energy, and deformation to rupture point) were studied under compression loading by using the Testometric Universal Testing Machine (UTM); while the textural parameters (hardness and fracturability) were determined by using the Warner-Bratzler shear force (WBS) method. Results showed that all the above mechanical and textural parameters of cucumber fruit are significantly (P≤0.05) dependent upon moisture content. Failure force, failure energy, maximum compressive force, rupture force, rupture energy, hardness and fracturability declined by 46.81, 52.34, 45.86, 45.57, 47.28, 47.45, and 51.29% respectively; whereas, the deformation at rupture point inclined by 30.58%, in the moisture content range of 72 and 87% (w.b). Mechanical and textural properties data of fruits are important parameters in the design of various handling, packaging, storage, processing and transportation systems.**

***Index Terms*— Cucumber, moisture content, compressive test, mechanical properties, textural properties**

I. INTRODUCTION

Cucumbers are members of the plant family *Cucurbitaceae*, which also includes squashes and melons. The most common type of slicing cucumber found in a grocery store is the garden cucumber, *Cucumis sativus.* There are hundreds of varieties of cucumber, and they come in dozens of colors, but the edible types are classified as being for either slicing or pickling [1]. Slicing cucumbers are usually larger and have thicker skins, while pickling cucumbers are usually smaller and have thinner skins (World's Healthiest Foods, 2018). National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria, research centre had identified *Nandini* cucumber (slicing type) as a crop with substantial growth and production potential. Even though there is no statistical record of total cucumber production in Nigeria, it is among the five most important fruit produced and consumed in Nigeria [2].

Cucumbers are good sources of phytonutrients, such flavonoids, lignans and triterpenes, which have antioxidant, anti-inflammatory and anti-cancer benefits. Cucumbers are a valuable source of conventional antioxidant nutrients including vitamin C, beta-carotene, and manganese. In addition, cucumbers contain numerous flavonoid antioxidants, including quercetin, apigenin, luteolin, and kaempferol [3]. Dried cucumbers are eaten in slices or ground up and made into a powder for use as a seasoning. As a snack, cucumber chips can be eaten as a healthier alternative to potato chips. After they rehydrate, the cucumber slices are simmered in additional stock with any extra vegetables, spices, and herbs the cook decides to include. Another use for dried cucumbers is in herb butter. Dried cucumbers ground into powder can be mixed into softened butter, along with other seasonings like dill weed, to evenly combine all the flavors [4].

Textural structure of fruit is a very important quality for maintaining its good taste and shelf life. As a significant quality parameter, the fruit hardness affects postharvest physiology as well as the consumer preferences [5]. Knowledge of the textural properties of cucumber fruit is vital in ensuring its acceptability; control and measurement. Studies have shown that changes in the moisture content of fruits results in change in its textural qualities [6], and will result in quality and shelf life loss of the cucumber fruit. Numerous factors, including variety, maturity, genetic modification, cultural particles and environmental conditions, processing conditions and calcium addition affect the textural integrity of fruits [7].

The study of mechanical characteristics of agricultural products is important, since they help in the development of equipment in order to obtain a maximum efficiency, without compromising the end quality of the product [8]. Agricultural products may suffer cracks and fractures, if the strains they are subjected to exceed their resistance [9] and the worst kinds of damage are caused mainly during the handling process for transportation by trucks, in bulk or in boxes [10]. Several factors affect the mechanical properties of agricultural products, such as drying temperature, water content, kind of force and grain area where this kind of force is applied [9], [11] and [12]. Reference [37] examined the rupture force, bio yield force, deformation, modulus of elasticity and failure energy in examination of effects of moisture content and loading on mechanical properties of carob pod [6]; while [13] studied the rupture force, rupture energy of *Ahmad Aghaie*`s variety of pistachio in three levels of moisture, and observed that rupture force, rupture energy and deformation were significantly affected by moisture. Similarly, [14] reported the several physical properties of hazelnut and kernels as a function of moisture content and found rupture force of nut and kernel decreased with an increase in moisture content.

Despite an extensive search, no published literature was found on the effect of moisture content on the mechanical and textural properties of cucumber fruits. Therefore, the objective of this research is to investigate the effect of moisture level of the range of 72 - 87% w.b, on the mechanical and textural properties of cucumber fruit (cv. *Nandini*) and to establish a convenient data that will aid the

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packaging, storage and processing of the cucumber fruit. Mechanical and textural properties data of fruits are important parameters in the design of various handling, packaging, storage, processing and transportation systems.

II. MATERIALS AND METHODS

A Sample Preparation

The cucumber fruits used for this study were procured 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, freedom from bruises, pests and insects attacks.

Conditioning Nandini cucumber fruits to different moisture levels

The conditioning of cucumber fruit to different moisture levels were prepared by adding distilled water as calculated using the equation 1 [15]. The prepared samples were packed in polyethylene bags and kept at 5^{o}C in a refrigerator for 48 h to equilibrate the samples.

$$Q = \frac{A(b-a)}{(100-b)} \quad (1)$$

Where:
a = initial moisture content of the sample, % w.b.
b = desired moisture content of the sample, % w.b.
Q = mass of water to be added, kg

The average moisture content of the six samples was found to be 72.30, 75.00, 78.00, 81.00, 84.00, and 87.00%, at the end of the conditioning. Moisture content level of 72.30% was the moisture content of the fruits at harvest. The experiments were replicated 4 times to avoid error.

Determination of the moisture contents of fruit samples

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 [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 experiment was replicated five times for each samples and the average value of the moisture content obtained was recorded.

B Compression test

A destructive deformation test was used by study the force, energy, and deformation values from force/deformation curve to determine change of mechanical and textural properties of cucumber fruit at various moisture content levels. All mechanical properties of the cucumber fruit evaluated using the Universal Testing Machine (UTM) (Testometric model, series 500-532), equipped with a 50 N compression load cell and controlled by a micro-processor, and two parallel plates that one is fixed and the other is versatile that moves at a compressive speed of 25 mm/min. The individual sample was loaded between two parallel plates of the machine and was compressed under the present conditions and the curve of force-deformation is simultaneously curved until the curve arrived to rupture point (point A in Fig. 1). Test results and force-deformation curves were automatically generated by the UTM.

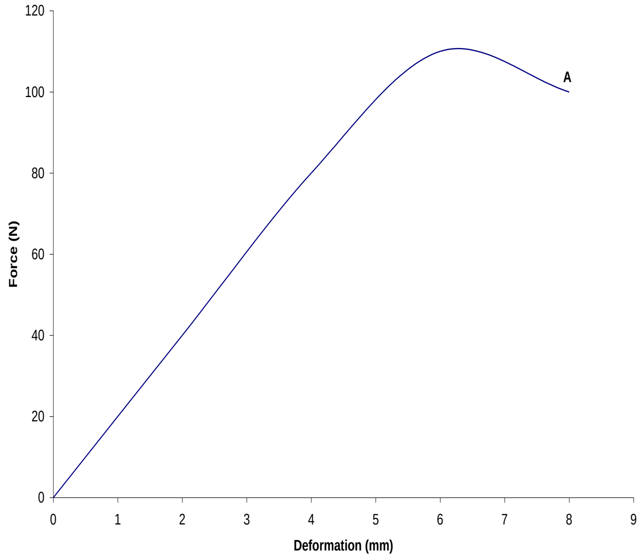

Figure 1: Force – deformation curve of cucumber fruit under compressive loading

The failure point was taken as the point on the force-deformation curve at which the compressed fruit weakened and failed internally. At this point, an increase in deformation resulted from either a decrease or no change in force, and the fruit could be said to have failed in its internal cellular structure [11] [17] [18]. Rupture point was the point on the force-deformation curve at which the fruit completely became ruptured and deformation resulted from a decrease in force [11] [17]. The compression test was replicated eight times for each moisture content level, and the mean of each property obtained was recorded. The variations of the properties with moisture content were then plotted.

C Determination of textural profile analysis

Texture profile analysis, (TPA), was performed on the intact *Nandini* fruit by using the Warner-Bratzler shear force (WBS) method, with the aid of the Universal Testing Machine (Testometric model, series 500-532) with accuracy of 0.001N. The operating parameters were as follows: load cell = 50 N, shear blade = 1 mm thick stainless steel notched shear blade, pre-test speed = 5 mm/s, test-speed = 0.5 mm/s and post-test speed = 0.5 mm/s, as recommended by [19]. For each test, a single cucumber fruit was positioned horizontally (Figure 2), and a cut was performed perpendicularly until it cut completely into two. Six fruits were measured individually for each treatment group. The texture parameters used in TPA analyses consist of hardness and fracturability, and the parameters were extracted automatically by the Testometric software. Definitions of these parameters are given below.

i. Hardness (expressed as cutting force) is the force at maximum compression at a given distance [20], and it was recorded as the second peak in the curve.
ii. The fracturability is force at the first major drop in force curve [20], and it was recorded as the first peak in the curve.

Figure 2: Cucumber fruit undergoing Warner Bratzler Test, using Universal Testing Machine (Testometric model, series 500-532)

III. RESULTS AND DISCUSSION

The values of the mechanical and textural parameters of the cucumber fruit were found to be a function of moisture content. Analysis of variance (ANOVA) of the mechanical and textural parameters of *Nandini* cucumber fruit used in the experiments presented in Table 1, shows that moisture content significantly ($p \leq 0.05$) affect the mechanical parameters (failure force, failure energy, maximum compressive force, rupture force, rupture energy and deformation at rupture), and textural parameters (hardness and fracturability) of the intact cucumber fruit. Regression relationships existing between the parameters and moisture content can also be expressed using polynomial equations of the first and second order, in the following forms:

$$y = a + bx \quad (2)$$

$$y = a + bx + cx^2 \quad (3)$$

Where:

y = Mechanical or textural property
a, b, c = regression coefficients
x = moisture content (%, w.b.)

The coefficients of term in the equation and p-value for each parameter are presented in Table 2. The equations were found to have very high coefficients of determination ($R^2 > 0.92$) and p-values, indicate that they described the relationships reasonably.

Table 1: Analysis of variance (ANOVA) of effect of moisture level on the mechanical and textural parameters of intact *Nandini* cucumber fruit

Source of variation	Dependent Variable	df	F	Sig.
Moisture content	Hardness	5	20.55	2.44E-10*
	Fracturability	5	17.69	2.12E-09*
	Failure force	5	9.045	6.78E-06*
	Maximum compressive force	5	9.650	3.46E-06*
	Rupture force	5	8.503	1.26E-05*
	Failure energy	5	3.638	0.007989*
	Rupture energy	5	4.109	0.003977*
	Deformation at rupture	5	4.145	0.003771*

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

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

Parameter	Linear equation	R^2	Polynomial equation	R^2	P
Failure force	$y = -11.434 x + 1179.9$	0.9630	$y = 0.4824 x^2 - 88.13 x + 4215.9$	0.9959	0.00019
Failure energy	$y = -0.0865 x + 8.8682$	0.9497	$y = 0.0017 x^2 - 0.3641 x + 19.85$	0.9572	0.00036
Maximum compressive force	$y = -11.509 x + 1207.9$	0.9936	$y = 0.1029 x^2 - 27.875 x + 1855.8$	0.9951	5.16E-06
Rupture force	$y = -11.197 x + 1183.9$	0.9787	$y = -0.0015 x^2 - 10.96 x + 1174.6$	0.9787	5.63E-05
Rupture energy	$y = -0.0958 x + 9.9928$	0.9876	$y = -0.002 x^2 + 0.2187 x - 2.4579$	0.9957	1.98E-05
Deformation at Rupture	$y = 0.4297 x - 15.919$	0.9834	$y = -0.0127 x^2 + 2.4519 x - 95.96$	0.9999	0.002018
Hardness	$y = -4.4869 x + 460.3$	0.9218	$y = 0.2802 x^2 - 49.035 x + 2223.7$	0.9908	0.000904
Fracturability	$y = -4.8032 x + 480.35$	0.9039	$y = 0.3316 x^2 - 57.535 x + 2567.7$	0.9867	0.001529

A Mechanical parameters

Failure force

As shown in Figure 3, moisture content level within the probability of 5% was significant on the failure force of the cucumber fruit. The failure force declined from 374.51 to 199.2 N (46.81% decreased) as moisture level increased from 72 to 87% (w.b) (Fig.3). This might be because of the differences in cucumber fruit tissue at different moisture level. The implication of the above result is that the compressive force needed to initiate failure in the intercellular structure of the cucumber fruit is dependent on the moisture content; and lesser force would be needed when the fruit was at higher moisture levels. The trend of failure force of the cucumber fruit with moisture content appeared to be similar to that of *balanites aegytiaca* nuts [21].

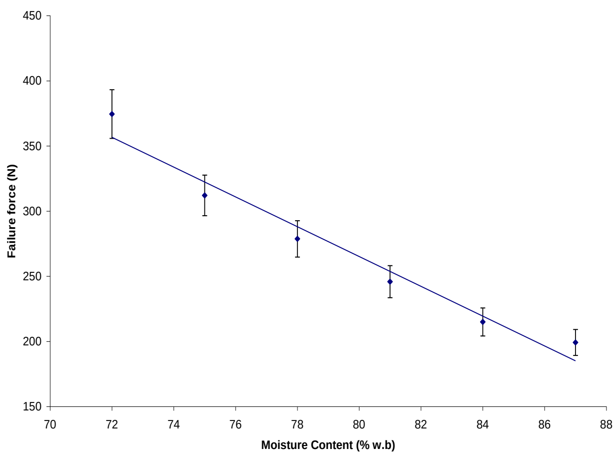

Figure 3: Effect of moisture content on failure force of cucumber fruit

Failure energy

The Failure energy values were found to decrease significantly ($P \leq 0.05$) from 2.79 to 1.33 Nm (52.34% decreased) in the moisture content range of 72 –87% (w.b.) (Fig. 4). The magnitude of decrease in failure energy may be attributed to the change cellular structure of the fruit with the increase in moisture content. Similar trend was also observed by [22] for coffee. Failure energy is important factor to consider in designing equipment for mass flow and storage structures for cucumber fruits.

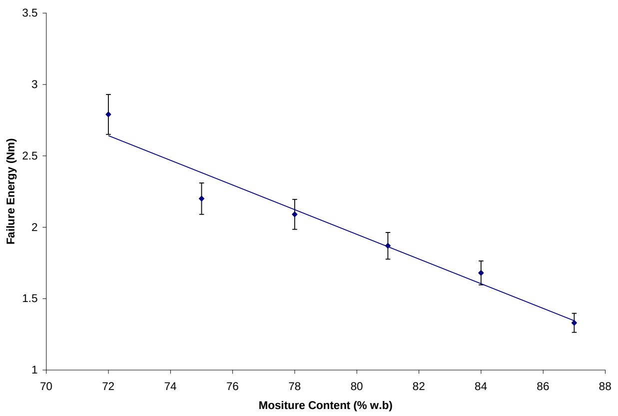

Figure 4: Effect of moisture content on failure energy of cucumber fruit

Maximum compressive force

Moisture content significantly ($p < 0.05$) influenced the maximum compressive force of the cucumber fruit as showed in the ANOVA table (Table 1). The variation of maximum compressive force of *Nandini* cucumber fruit with moisture content, when subjected to compressive loading is represented in Figure 5. Figure 5 shows the maximum compressive force of the fruit decreased from 386.00 to 208.99 N (45.86% decreased) with increase in moisture content from 72 to 87% (w.b). The low amount of compressive force required at higher moisture content might have resulted from the fact that the fruit tended to be very soft in high moisture content. Similar finding was reported for wheat by [23]. The minimum compressive strength of *Nandini* cucumber fruit is lower than the values reported for *mucuna flagellipes* nut [24] and conophor nut [25]. The regression relationship between maximum compressive force and fruit moisture can be expressed by the regression equations in Table 2.

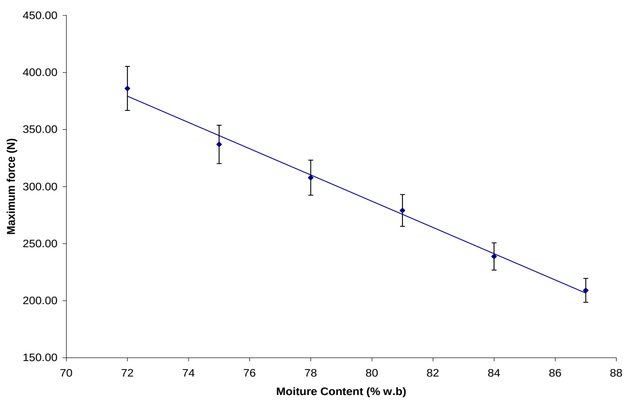

Figure 5: Effect of moisture content on maximum compressive force of cucumber fruit

Rupture force

The rupture force of the cucumber fruit was found to decrease significantly ($P \leq 0.05$) from 384.31 to 208.81 N (45.57%, decreased), as moisture content increased from 72 to 87% (w.b). The result shows that rupture force is highly dependent on moisture content of the fruit. From the curve (Fig. 6), greater forces were necessary to rupture of the fruit at lesser moisture content, which can be attributed to increase in flexibility of fruit's internal textural structure caused by increasing moisture content. This result is similar to the results obtained by [26] during evaluation of mechanical behavior of sunflower seeds with an increase of moisture content from 3.8% to 16.6% (w.b.), and observed that the rupture force of the product reduced and its deformation increased. In addition [27] reported similar trend for apricot pit. Changes in the cucumber fruit rupture force with moisture content can be represented by the regression relationships shown in Table 2.

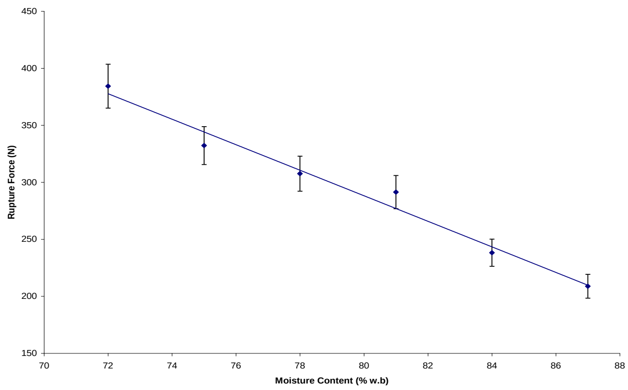

Figure 6: Effect of moisture content on rupture force of cucumber fruit.

Rupture energy

Statistical analysis (ANOVA) revealed that moisture content significantly ($P < 0.05$) affects the cucumber fruit's rupture energy. The rupture energy was found to decrease significantly from 3.05 to 1.61 Nm (47.28%, decreased), as moisture content increased from 72 to 87% (w.b). As shown in Figure 7. The lower rupture energy at higher moisture content can be attributed to the fruit becoming more sensitive to compressive force at higher moisture levels; leading to drop in rupture force. Also as the moisture increases, the fruit became softer and weak, and unable to withstand higher compressive force. This result is in agreement with the findings for shea nut [28]; and *Ghermez-Shahrood* apricot pit [29]. The regression relationships between rupture energy and moisture content are presented in Table 2.

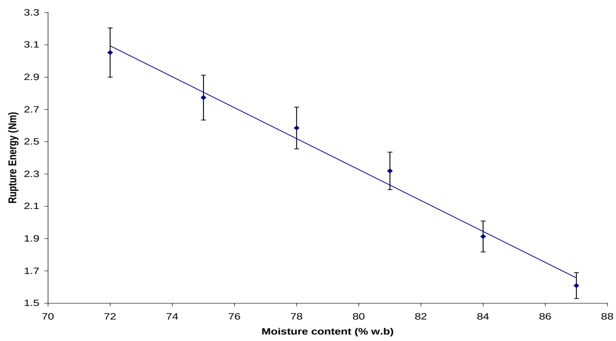

Figure 7: Effect of moisture content on rupture energy of cucumber fruit.

Deformation at rupture

Figure 8 shows the effects of moisture content on the deformation at rupture of the cucumber fruit. The deformation increased gradually 14.64 to 21.09 mm (30.58% increased) as the moisture content increased from 72 to 87% (w.b). Flexibility of the fruit under higher moisture levels is one of the reasons for higher deformation of the fruit as moisture levels increases [30]; also another reason is due to skin viscoelastic property which causes higher deformation of the fruit under compression. Similar results were reported by others [27], [29] and [31]. Table 2 presents the regression relationship between moisture content and deformation at rupture of cucumber fruit.

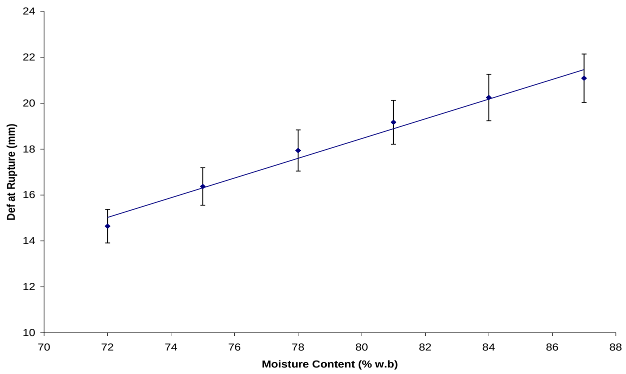

Figure 7: Effect of moisture content on deformation at rupture of cucumber fruit.

B Textural parameters

Hardness

The hardness (also expressed as the cutting force) as affected by the moisture content is presented in Figure 8. The hardness decreased linearly from 145.77 to 76.6 N (47.45% decreased), with the increase in moisture content from 72 to 87% (w.b.). Higher levels of hardness (cutting force) are associated with increasing sample toughness [20], and decrease in fruit hardness is attributed to loss in the cell-wall integrity [6]. It has been well established that fruit texture is closely related to cell wall structure and composition and fruit softening is the consequence of disassembly of primary cell wall and middle lamella structures [32]. The regression relations in Table 2 can correlate the pattern of decrease of the hardness of the cucumber fruit, with increased in moisture content of the fruit.

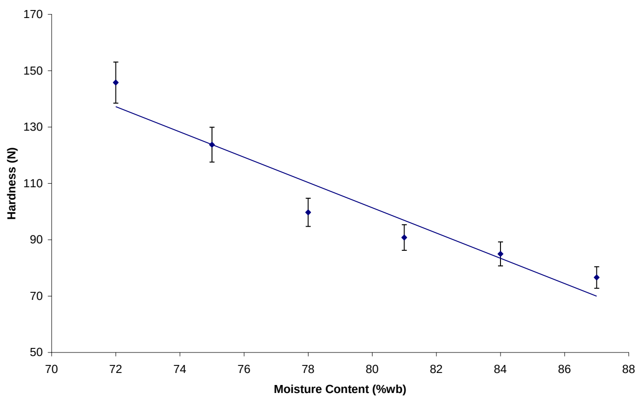

Figure 8: Effect of moisture content on hardness of cucumber fruit

Fracturability

Fracturability of cucumber fruit decreased with increase in moisture content in a polynomial pattern (Fig. 9). It decreased from 144.22 to 70.25 N (51.29% decreased) at moisture content increased from 72 to 87% (w.b.). The decrease in hardness and fracturability of the fruit can be attributed to the fruit becoming softer as moisture levels increases. Table 2 shows the regression relationship between the patterns of decrease in the fracturability of the cucumber fruit, with increased in moisture content.

Mechanical and textural properties data of fruits are important parameters in the design of various handling, packaging, storage, processing and transportation systems. Fruit texture is considered a major contributor to the susceptibility to bruising and might vary considerably within the fruit [33]. Reference [34] extensively reviewed the different aspects of fruit texture and listed factors that greatly influence fruit texture in general. Textural changes might result from alterations in primary cell wall metabolism [35], causing alteration in the fruit cellular turgor. According to [36], the mechanical and textural resistance of fruits depends on cellulosic compounds of the cell wall and composites that bind the cells together.

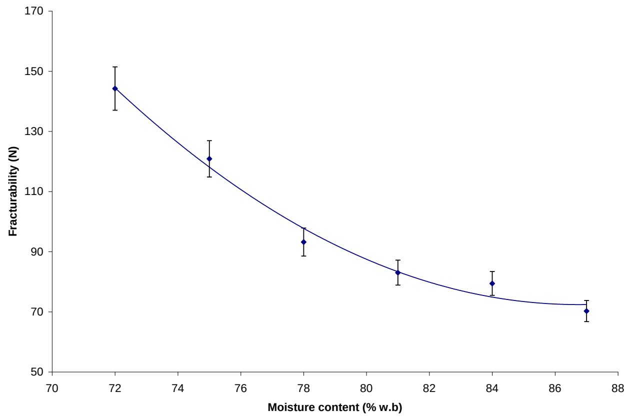

Figure 9: Effect of moisture content on fracturability of cucumber fruit

IV. CONCLUSIONS

The following conclusions are drawn from the investigation on the mechanical and textural properties of intact *Nandini* cucumber fruit for moisture content range of 72 to 87% w.b. Analysis of variance (ANOVA) of the result shows that moisture content significantly ($P \leq 0.05$) influenced all the mechanical and textural parameters investigated in this study. The following mechanical parameters (failure force, failure energy, maximum compressive force, rupture force, and rupture energy) decreased linearly with increase in moisture content; whereas, the deformation at rupture increased linearly with increase in moisture content. In addition the textural parameters (hardness and fracturability) decreased with increase in moisture content. As the moisture content increased from 72 to 87% w.b.; the failure force was found to decrease from 374.51 to 199.2 N (46.81% decreased), failure energy decreased from 2.79 to 1.33 Nm (52.34% decreased), maximum compressive force decreased from 386.00 to 208.99 N (45.86% decreased), rupture force was found to decrease from 384.31 to 208.81 N (45.57%, decreased), rupture energy decreased from 3.05 to 1.61 Nm (47.28%, decreased), deformation at rupture increased from 14.64 to 21.09 mm (30.58% increased), hardness decreased from 145.77 to 76.6 N (47.45% decreased), and fracturability decreased from 144.22 to 70.25 N (51.29% decreased). Also in this study, the mechanical and textural parameters of the cucumber fruit are expressed in the form of regression equations as a function of moisture content. The relationships between mechanical and textural parameters of *Nandini* cucumber fruit and moisture content were established by linear and second degree polynomial equations, and the regression equations suggested a better fit. Mechanical and textural properties data of fruits are important parameters in the design of various handling, packaging, storage, processing and transportation systems.

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