Storage conditions effect on physical, mechanical and textural properties of intact cucumber (cv Nandini) fruit

Okeoghene Eboibi, Hilary Uguru

***Abstract*— - Physical, mechanical and textural characteristics of intact cucumber (Cucumis sativus Cv Nandini) fruit during storage at tropical ambient condition (28oC ± 3°C, 86 -91% relative humidity [RH]), and refrigerated condition (5oC and 65 % RH) were measured using compression and textural profile analysis methods, for 0, 2, 4, 6 and 8 d of storage time. In this study, we evaluated the following parameters; Physical paramters (mass, length, breadth, fruit sphericity, geometric mean diameter, surface area, and shrinkage of the surface area); mechanical parameters (compressive force compressive strain and compressive energy) were measured with the aid of the Universal Testing Machine, (Testometric model, series 500-532); and textural parameters (hardness and fracturability) using the using the Warner-Bratzler shear force test, for eight days, at two days interval. After 8 d of storage, all the physical properties decreased significantly (P≤0.05) under ambient and refrigerated condition respectively. Based on the mechanical parameters, the compressive force and compressive energy decreased significantly (P < 0.05) by 33.90 and 22.1%, and 24.52 and 18.33% in ambient and refrigerated storage condition respectively; whereas, the compressive strain increased by 27.49 and 12.67% respectively under ambient and refrigerated condition respectively. The textural parameters decreased significantly (P < 0.05) with increased in storage time in both storage conditions. The results depict that the parameters studied are strongly depended on the temperature, and low temperature is beneficial for delaying physical, mechanical and textural changes of the fruit during storage.**

***Index Terms*— Nandini; storage; Physical properties; Hardness; fracturability; Mechanical properties.**

I. INTRODUCTION

Cucumber (*Cucumis sativus* L.) is an important vegetable crop worldwide [1], and cultivated in subtropical and tropical environments, therefore they are native to many countries of the world [2]. *Nandini* cucumber is one the cultivars of cucumber becoming increasingly popular in many parts of Nigeria, and neighbouring countries. National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, research centre, had identified *Nandini* cucumber 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.

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Cucumber fruits have high nutritional and medicinal values, as well as a useful component ingredient in the canteens preparation of salad and liquor drink in hotels and homes [3]. Fresh cucumber fruit provides a range of health benefits including valuable antioxidant, anti-inflammatory, anti-cancer agents, contains a lot of victims, good for diabetic patients as it contains low sugar, and help in the burning of excess fat in the body [4], [5]. The copper content of cucumber seeds helps in stimulating the process of neurotransmission which in turn improves the overall brain coordination [6]. The outer covering that is melanin or the epicarp of cucumber is used or mixed with pomade or cream to control oily or fatty face [3].

Fruits texture is a very important trait for maintaining good taste and shelf life of the fruit. As a significant quality parameter, fruit hardness affects postharvest physiology as well as the consumer preferences [7]. Studies have shown that during storage, ripening of fruits continues, and become overripe very rapidly under higher temperature, which results in change in its textural qualities. This results in loss of quality and shelf life of the cucumber fruit. Softening of fruits during storage, distribution and ripening can cause lot of problems, not only degradation of quality and consumers acceptability of product but also problems of economical nature since softening can increase tomatoes susceptibility to damage [8].

Many researchers literature have investigated how physical, mechanical and textural properties of fruits and vegetables are relevant in the design of sorting, grading, bulk handling, storage and processing systems. For instance, the cutting force (hardness) of kiwifruits stored for 16 days at 21ºC and 78% RH, decreased from 51. 4 to 40.1 N [9]; also [10] reported that the hardness of pomegranate fruit declined from 125.87 to 112.29 N when stored at 10 ºC and 92 % RH for 4 months. In addition, [11] reported that 7% weight loss of cucumber fruit during storage affects its marketability. Limited researches have been conducted on the physical, mechanical and textural properties of *Nandini* fruits. Some engineering properties of *Dharwad* and Super *dominus* cultivars of cucumber, such as length, breadth, sphericity [12]; and firmness, failure strength of *Viola* cultivar [13].

The objective of this study was to investigate some storage time dependent physical, mechanical and textural properties of intact *Nandini* fruit, under two storage conditions, that will help in the design and development of equipments for sorting, grading, processing, storing, packaging and handling of the fruits.

Nomenclature

C_e=	Compressive force (N)	M_L =	Mass lost (%)
C_e=	Compressive energy (Nm)	M_i =	Final mass
C_s=	Compressive strain (mm)	S_A =	Surface area (mm^2)
F_r =	Fracturability (N)	S_{KG} =	Shrinkage of cucumber fruit (%)
H =	Hardness (N)	S_{A0} =	Initial sample surface area (mm^2).
R^2 =	Coefficient of determination	S_{Ai} =	Final surface area (mm^2)
L =	Length of fruit (mm)	x =	Storage time (days)
D =	Breadth of fruit (mm)	ɸ =	sphericity (%)
D_g =	Geometric mean diameter (mm)	$_a$ =	Ambient condition
M=	Mass (g)	$_f$ =	Refrigerated condition

II. MATERIALS AND METHODS

A Sample Preparation

For the present study, *Nandini* cucumber fruits were procured from the research farm of National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State. Matured healthy cucumber fruit samples without bruises, were selected randomly on the basis of uniformity of shape and size, washed with 100 parts per million concentration of chlorine to eliminate microbial contaminations and prevent infections during storage, and dried. The cleaned fruits were then divided into two groups; one portion was kept in ambient temperature of 29ºC ± 5˚C and 86 -91% humidity, while the other portion was stored inside a refrigerator at (5^{o}C and 65 % RH) as recommended by [14]. The physical, strength and textural properties of the fruits were determined at the two-day intervals (0, 2, 4, 6 and 8 d). For each experiment, refrigerated samples were left for 2 hours to equilibrate with room temperature [15], [13]. All the strength and textural experiments were replicated six times at each storage level and the average values were reported.

B Determination of Physical Characteristics

Mass determination

Unit mass of the fruit was determined by direct measurement using an electronic digital balance with accuracy of 0.01g. The cumulative losses in mass were calculated as percent of initial mass lost by using equation 1 below [16].

$$M_L\% = \frac{M_0 - M_i}{M_0} X\ 100 \qquad (1)$$

Size and shape determination

To determine the average size and other physical properties of the seed, a sample of forty fruits were randomly selected and marked. Measurement of the two linear dimensions, namely length (L) and breadth (D), as shown in Figure 1 were measured by using a digital caliper with accuracy of 0.01 mm.

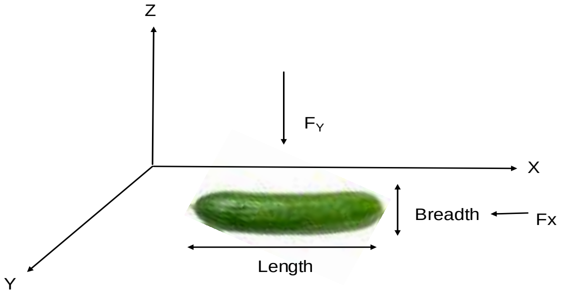


Figure 1: Representation of the two axial forces (Fx and Fy) and two perpendicular dimensions of *Nandini* fruit.

Geometric mean diameter (size)

The geometric mean diameter (Dg), (also expressed as size 'S'), was calculated by the following relationship [17].

$$D_g = \sqrt[3]{LD^2} \qquad (2)$$

Surface area

Surface area, (S_A), defined as the total area over the outside of the cucumber fruit. Surface area was theoretically calculated as apparent surface area using equation 3 [17].

$$S_A = \pi D_g^2 \qquad (3)$$

Sphericity

The sphericity, Φ, (%), defined as the ratio of surface area of a sphere having the same volume as that of fruit to the surface area of the fruit, was determined using the following formula [18].

$$\Phi = \frac{\sqrt[3]{LD^2}}{L} x100 \qquad (4)$$

Shrinkage

Shrinkage, $S_{KG,}$ (%), of the surface area of the cucumber fruit was obtained by using the formula given by [19].

$$S_{KG} = \left(1 - \frac{S_{Ai}}{S_{Ao}}\right) \times 100 \qquad (5)$$

C 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, [20]. For each test, a single cucumber fruit was positioned with its horizontal (Figure 2). The cut was performed perpendicularly until it completely cut 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 [21], and it was recorded as the second peak in the curve.

ii. The fracturability is force at the first major drop in force curve [21], 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)

D Mechanical Properties

The Universal Testing Machine, (UTM), (Testometric model, series 500-532) equipped with a 50 N compression load cell and integrator, with measurement accuracy of 0.001 N, was used to carry out the mechanical parameters (compressive force, compressive energy, and compressive strain) of intact *Nandini* cucumber fruit. Each fruit was placed in the UTM, under the flat compression tool, in a horizontal level, ensuring that the centre of the tool was in alignment with the peak of the curvature of the cucumber fruit, compressed at the rate of 25 mm/min [13], which continues till the sample ruptures. Six fruits were measured individually for each treatment group. The mechanical parameters were extracted automatically by the Testometric software in relation to the response of each sample.

Definitions of these parameters are given below:

i. The compressive force is the maximum force a material is capable of sustaining, and it is taken as the force at peak of the sample [21].
ii. The compressive strain is the corresponding point of the compressive force on the deformation axis on the force-deformation graph on the deformation point,
iii. Compressive energy is the area under the force-deformation curve.

E Experimental design and statistical analysis

For the physical properties, the samples were selected randomly and the measurements were done on 40 cucumber fruits. Five storage times (0, 2, 4, 6, and 8 d) and two storage conditions (ambient and refrigerated) were the considered experimental factors

A 5 x 2 factorial experiment in a Completely Randomized Design (CRD) was employed to study the effects of storage time and storage conditions on selected mechanical and textural properties of the *Nandini* fruit. Five storage times (0, 2, 4, 6, and 8 d) and two storage conditions (ambient and refrigerated) were the considered experimental factors which were randomized with six replications.

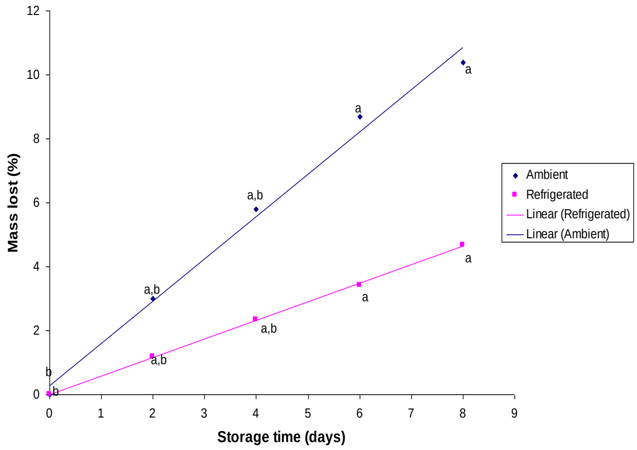
The data obtained from the research were subjected to variance analysis using SPSS statistical software. The difference between mean values of parameters was investigated by using Duncan's multiple range tests at 95% confidence level.

III. RESULTS AND DISCUSSION

A Physical properties

The analysis of variance (ANOVA) of the physical characteristics of *Nandini* cucumber fruit are presented in Table 1. As shown in Table 1, storage time and storage condition significantly influenced ($P \leq 0.05$) the seven physical parameters (mass, length, breadth, geometric mean, surface area, shrinkage and sphericity) investigated; also the interaction of storage time and condition significantly influenced ($P \leq 0.05$) the breadth, size, surface area and shrinkage, but does not significantly affects the length and spherecity of the *Nandini* fruit.

Mass Loss



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 3: Effect of time and condition on mass of *Nandini* fruits

Table 1: Analysis of Variance (ANOVA) for Some Physical parameters of cucumber fruit

Source of variation	df	Mass	Length	Breadth	Size	Surface area	Shrinkage	Sphericity
C	1	3.9E-02*	3.20E-04*	3.87E-11*	1.62E-05*	1.06E-04*	4.32E-102*	3.37E-12*
D	4	6.73E-04*	1.38E-06*	6.24E-28*	1.72E-33*	2.21E-34*	2.05E-142*	3.92E-03*
C x D	4	8.23E-01 ns	2.6E-01 ns	1.23E-06*	5.70E-08*	4.96E-08*	4.64E-45*	2.42E-01 ns

* = significantly different at ($P \leq 0.05$), ns = not significantly different

C = Storage condition, D = Storage time

Our present study showed significant ($p< 0.05$) differences in fruits mass loss among the storage conditions and durations. The result shows that the rate of mass loss at ambient due to higher temperature is much more than refrigerated condition (Figure 3). Cucumber fruits stored under refrigerated condition had lower mass loss (4.66%) than those stored under ambient condition (10.38%) after 8 d of storage, which can be attributed to lower loss of moisture from the fruits to the environment, caused by lower temperature. This shows the importance of low temperature in reducing mass loss of cucumber fruitsduring storage. The result of present study conforms [9] work who reported 14% and 4.5% of weight loss in kiwifruits stored at ambient and refrigerated conditions respectively after 16 d of storage. Similar results was reported by [22] in 'Halow' pomegranate fruits stored at (7°C and 95% RH) and (21°C and 65% RH) for 6 weeks. Mass loss in fresh fruits and vegetables is mainly due to water loss caused by transpiration and respiration processes caused by storage temperature [23]. Storage temperature affects the post-ripening behaviour, respiration, transpiration, senescence and other physiological actions of fruits, leading to mass loss [22], [24]. Mass is an important factor to be considered in the design of sorting, cleaning and conveying machineries, and mass loss can cause undesirable physical and textual changes of a fruit, eventually leading to loss of its visual appeal. The linear relationship between mass and storage time can be represented by the following equations:

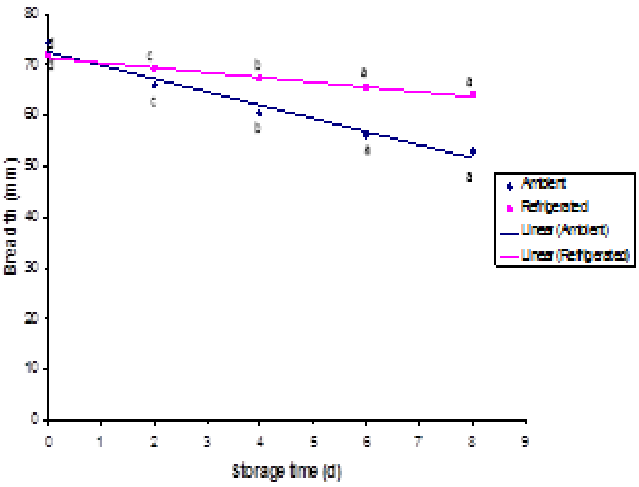
$$M_a = 1.3225\,x + 0.282 \qquad R^2 = 0.9917 \qquad (6)$$
$$M_f = 0.5785\,x + 0.004 \qquad R^2 = 0.9997 \qquad (7)$$

Fruit Dimensions

The effects storage time and storage conditions on the dimensions (L and D) of *Nandini* fruit are presented in Figures 4, 5 and 6. Length and breadth of *Nandini* fruit decreased linearly with storage time, under both storage conditions, whereas, the size (the geometric mean) decreased polynomially with increase in storage time, probably due to decline in the dimensions of the breadth and length of the fruits during storage. All the dimensions of *Nandini* fruit were significantly correlated ($R \geq 0.95$) to storage time and storage conditions. Similar results were reported for of treated and control cucumber fruits [25].

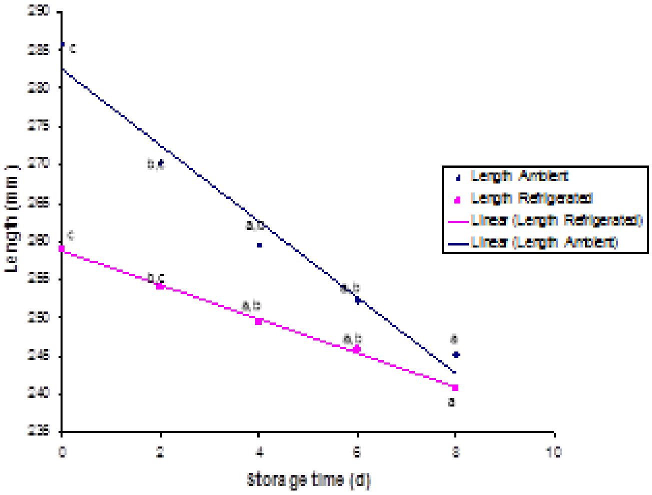
The relationships between the fruits axial dimensions (L, D, and S) and storage time can be expressed using the following regression equations:

$$W_a = -2.615\,x + 72.44 \qquad R^2 = 0.9652 \qquad (8)$$
$$W_r = -0.975x + 71.44 \qquad R^2 = 0.9884 \qquad (9)$$
$$L_a = -4.965\,x + 282.42 \qquad R^2 = 0.9687 \qquad (10)$$
$$L_f = -2.227\,x + 258.68 \qquad R^2 = 0.9966 \qquad (11)$$
$$S = 0.2779\,x^2 - 5.4919\,x + 115.07 \qquad R^2 = 0.9970 \qquad (12)$$
$$S = 0.0736\,x^2 - 1.7276\,x + 109.11 \qquad R^2 = 0.9959 \qquad (13)$$



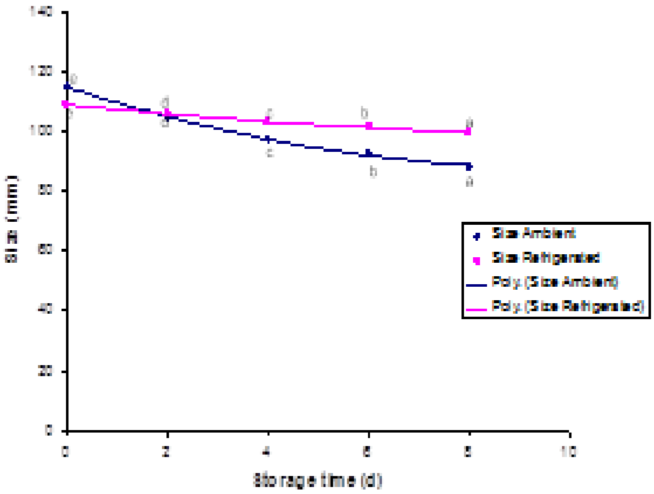
Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 4: Effect storage time and conditions on breadth of *Nandini* fruit



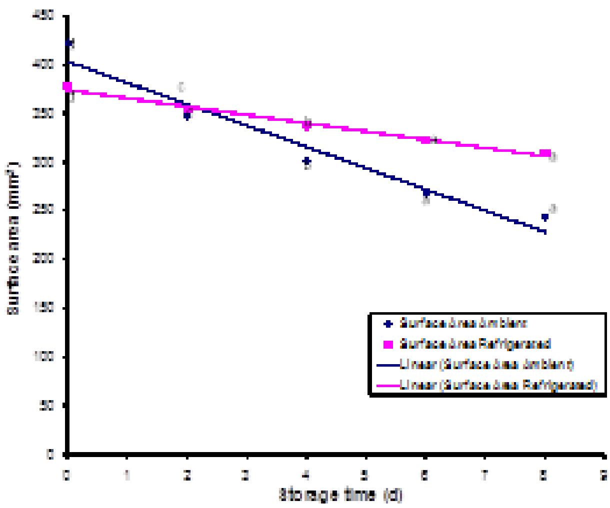
Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 5: Effect storage time and conditions on length of *Nandini* fruit



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 6: Effect of time and condition on size of *Nandini* fruit



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 7: Effect of time and condition on surface area of *Nandini* Fruit

Surface area

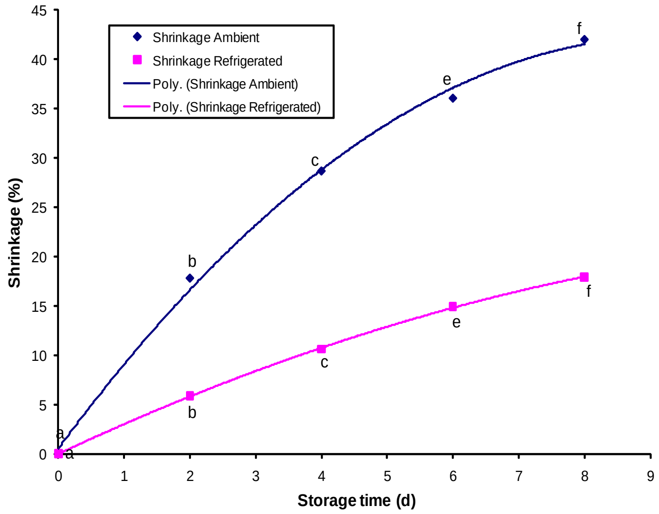
The *Nandini* fruit surface area, S_A, decreased linearly with increasing storage time, and was higher in fruits stored under ambient condition (42.07%) than those stored under refrigerated condition (17.91%)as shown in Figure 7. References [26], [27] found similar results on date palm cv. *Stamaran*, and tomatoes fruits respectively. The variation in surface area with storage time can be represented by the following regression equations:

S_a= -21.85 x + 403.6 R2= 0.9522 (14)
S_f = -8.45 x + 373.8 R2 = 0.9890 (15)

Shrinkage

Shrinkage, (%), of the *Nandini* fruit increased with increased in storage time (Figure 8), and the magnitude of the shrinkage may be attributed to the reduction in size (S) of the fruit. Shrinkage of *Nandini* fruit stored under refrigerated condition was found to decrease slightly with increase in storage time, as against ones stored under ambient condition. Shrinkage was found to be the main reason for change in most of the physical properties investigated in this research. Mass loss and shrinkage are major postharvest problems affecting the *Nandini* fruit during storage period. Polynomial relationship between the shrinkage and storage time for *Nandini* fruit can be represented by the following equations:

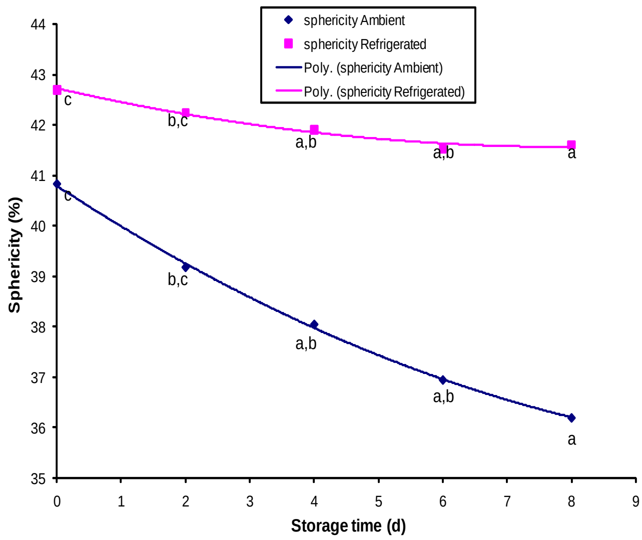
$S_{Ka} = -0.4866 x^2 + 9.0134 x + 0.5731$ $R^2 = 0.9972$ (16)
$S_{Kf} = -0.1107 x^2 + 3.1287 x + 0.0043$ R^2=0.9998 (17)



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.
Figure 8: Effect of time and condition on shrinkage of *Nandini* fruit

Sphericity

This study showed that storage time and conditions had significant ($p < 0.05$) effect on the fruit sphericity. The polynomial relationship between sphericity and storage time of *Nandini* fruit as shown in Figure 9, varied for different storage condition, higher under refrigerated condition than under ambient condition. The reason of this could be explained as follows: while the cucumber fruit lost moisture, its individual length and breadth decreases; consequently, its shape changes.



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.
Figure 9: Effect of time and condition on sphericity of *Nandini* fruit

The sphericity of *Nandini* fruit was similar to result for sphericity for *Green gold*, *Dharwad* and *Super dominus* cultivars of cucumber [12]. Higher values of sphericity of a fruit, indicates higher tendency of it roll on any of its three axes [28], therefore, the ability of the fruit to roll over flat surfaces decreases during storage. Regression relationship between the fruit sphericity with storage time can be represented by the following equations:

$\phi_a = 0.0327 x^2 - 0.8359 x + 40.801$ R^2= 0.9991 (18)
$\phi_f = 0.0182 x^2 - 0.2907 x + 42.716$ $R^2 = 0.9804$ (19)

Results from all the physical parameters studied showed that the physical qualities of the cucumber fruit can be optimally maintained at lower temperature during storage, as the rate of decline were higher in the ambient condition than in the refrigerated storage condition. The high values of $R^2 \geq 0.96$ from regression equations suggested a better fit.

B Textural Properties

Table 2 shows the ANOVA result for effect of storage time and storage conditions on the two textural parameters (hardness, expressed as cutting force and fracturability) of *Nandini* cucumber fruit. As shown in Table 2, the effect of storage time and storage conditions were significant (P<0.05) on the two textural parameters, also the interactions of storage duration × storage conditions were not significant (P<0.05) on all the textural parameters of the cucumber fruit.

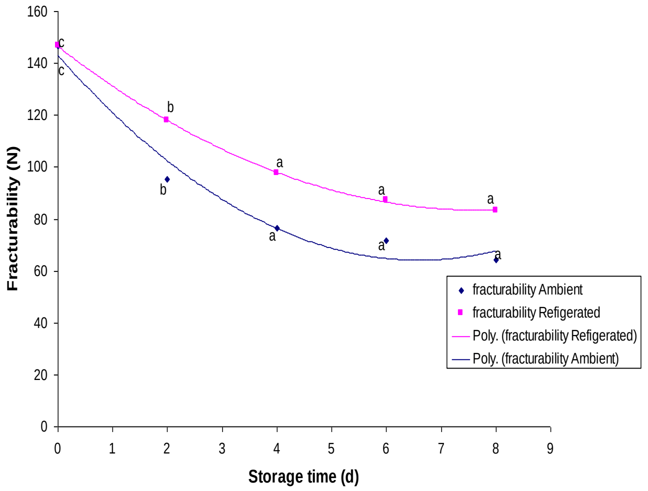
Table 2: Analysis of variance (ANOVA) of effect of textural properties of *Nandini* fruit, stored under ambient and refrigerated condition

Source	df	Hardness	Fracturability
D	4	7.30E-15*	8.77E-09*
C	1	1.02E-09*	2.2E-03*
D x C	4	0.85314^{ns}	0.97621^{ns}

* = significantly different at ($P \leq 0.05$), ns= non-significant
D = Storage time
C = Storage condition

Fracturability

The fracturability of *Nandini* fruit as affected by storage time is presented in Figure 10. It is clear from figure 10 that the decline in fracturability was higher at ambient condition (56.19% decreased) than in refrigerated condition (43.20% decreased).



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 10: Effect of time and condition on fracturability of *Nandini* fruit

Reference [29] reported similar trends of apple fruit during storage. Deterioration in the cucumber textural qualities during storage could be attributed to the breakdown of its tissue's structure. Textural changes might result from alterations in primary cell wall metabolism, a common ripening-related process in all flowering plants and a decrease in cellular turgor [30], [31]. Polynomial relationship between fracturability and storage time can be expressed by using the following regression equations:

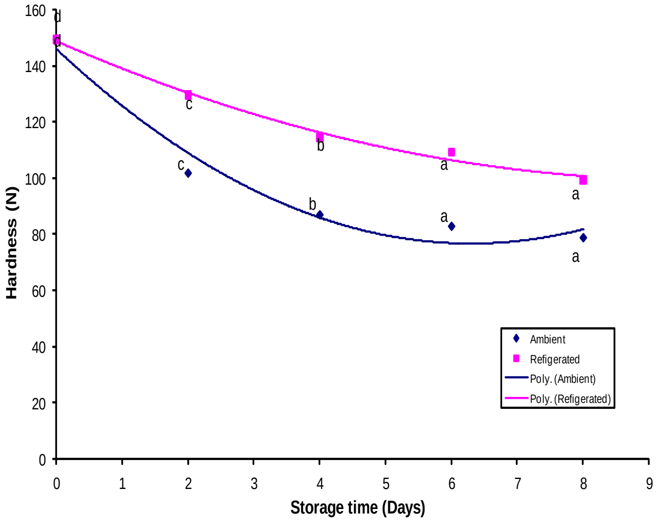
F_{ra}= 1.811 5x^2 - 23.901 x + 143.02 $R^2 = 0.9714$ (20)

F_{rf}= 1.0619 x^2 - 16.372 x + 146.53 $R^2 = 0.9997$ (21)

Hardness

The hardness of *Nandini* fruit changed significantly during storage, and decreased Polynomially with increase in storage time (Figure 11). The values found in the present study were lower than what was found for pomegranate fruits [10], but higher than those reported for kiwifruits [9], comparing similar tests. Higher levels of hardness (cutting force) are associated with increasing sample toughness [21].

The decreased in hardness can be attributed to the fruits textural structures becoming softer at increased storage time. 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], and decrease in fruit hardness is attributed to loss in the cell-wall integrity [33]. Similar observations were reported by [34] where cutting force and energy for citrus decreased with the storage period. The results showed that the textural quality of the cucumber fruit can be optimally maintained at lower temperature during storage, as the rate of decline were higher in the ambient condition than in the refrigerated condition. The textural property is an important quality in fruits' processing and handling industries.



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 11: Effect of time and condition on hardness of *Nandini* fruit

The regression relationship between storage time and storage conditions of the fruit's hardness can be represented by the following equations:

$H_a = 1.7479 x^2 - 21.994 x + 146.17$ $R^2 = 0.9675$ (22)

$H_f = 0.533 x^2 - 10.291 x + 148.93$ $R^2 = 0.9903$ (23)

C Mechanical properties

Table 3 shows the ANOVA result for effect of the storage time and storage conditions on the three mechanical parameters of *Nandini* fruit investigated. From Table 3, storage time had significant ($P<0.05$) effect on the compressive force, compressive energy and compressive strain of the fruit. Also the interaction of storage time and condition did not significantly influenced ($P \leq 0.05$) the mechanical parameters of the fruit.

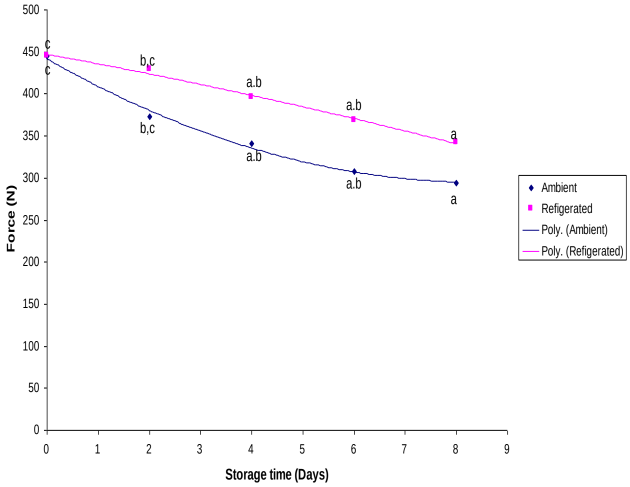
Table 3: Analysis of variance of effect of mechanical properties of cucumber fruit, stored under ambient and refrigerated condition

Source	df	Compressive Force	Compressive Strain	Compressive Energy
D	4	2.02E-03*	4.06E-03 *	3.82E-03*
C	1	1.41E-02*	0.0686^{ns}	1.86E-02*
D x C	4	0.99806^{ns}	0.4714^{ns}	0.9806^{ns}

* = significantly different at ($P \leq 0.05$), ns= non-significant
D = Storage times
C = Storage condition

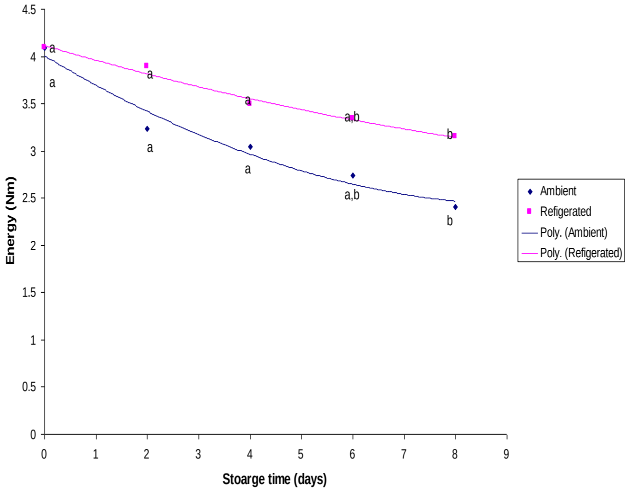
Compressive force and compressive energy

The compressive force and energy as affected by the storage time are presented in Figures 12 and 13. The decline was significantly higher under ambient condition than under refrigerated condition, which might be attributed to higher rate of evaporation, transpiration and metabolic activity of fruits kept in ambient condition. According to [35], fruit became softer due to the cellular water loss and disintegration the cell wall structure composition.



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 12: Effect of time and condition on compressive force of *Nandini* fruit



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 13: Effect of time and condition on compressive energy of *Nandini* fruit

The fruit compressive force and energy decreased polynomially with the increase in storage time in both storage conditions as represented by the following equations:

$C_{fa} = 2.0546\ x^2 - 34.752\ x + 441.9 \quad R^2 = 0.9933 \quad (24)$

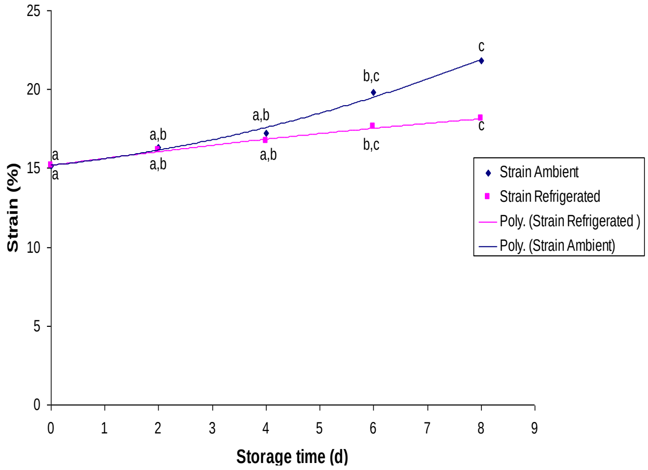
$C_{fr} = -0.2682\ x^2 - 11.151\ x + 447.33 \quad R^2 = 0.9927 \quad (25)$

$C_{ea} = 0.017\ x^2 - 0.3282\ x + 4.0077 \quad R^2 = 0.9629 \quad (26)$

$C_{ef} = 0.0048\ x^2 - 0.1601\ x + 4.1166 \quad R^2 = 0.9829 \quad (27)$

Compressive strain

The compressive strain of the fruit increased with increase in storage time (Figure 14). Figure 14 shows that *Nandini* fruit kept in ambient condition had greater compressive strain (27.49% increased) than ones kept in refrigerated condition (12.67% increased). This may be attributed that at higher temperature (ambient condition), fruit become softer due to the cellular water loss and disintegration the cell structure composition [35], resulting in larger deformation under smaller loading. During storage time, 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 [36].



Different letters on lines represent statistical differences ($p < 0.05$) using Duncan's multiple range test.

Figure 14: Effect of time and condition on compressive strain of *Nandini* fruit.

Regression relationship between compressive strain and storage time can be expressed by the following polynomial equations:

$C_{sa} = 0.06\ x^2 + 0.36\ x + 15.196 \quad R^2 = 0.9909 \quad (29)$

$C_{sf} = -0.0118\ x^2 + 0.4643\ x + 15.184 \quad R^2 = 0.9899 \quad (30)$

From Figures 12 and 13, greater compressive force and compressive energy were necessary to breaks the fruit at harvest, than as storage progresses. The high values ($R^2 \geq 0.94$) (equations 24 to 30) show strong relationship between the mechanical parameters of the *Nandini* fruit and storage time in both conditions. These results were similar to those reported by [13], on *Viola* cucumber stored for nine days; and [37] reported declined in the strength properties of apples during storage. In addition, [38] reported that several factors affect fruit compression test results; this may depend on the mechanical strength of the skin, firmness of the flesh, juice viscosity, and size of the fruit.

Engineering application

The data gotten from this research will provide useful information for quality control in food processing industry, and to serve as objective indicators of fruit quality, handling, sorting, and storability for engineering designers to develop more suitable sorting, handling, transportation and storage system for *Nandini* cucumber fruits. For instance, since textural properties play a major role in determining food quality in food processing industries, it is advisable to store cucumber fruits at lower temperature as to retain their textural qualities.

IV. CONCLUSION

Physical, mechanical and textural properties of cucumber are important quality attribute in fruit processing industries, and the research into their behaviour with respect to their storage time is necessary. Results from this study depict that all the parameters studied are strongly depended on temperature, and low temperature is beneficial for delaying physical, mechanical and textural changes of the *Nandini* fruit during storage. Regarding the physical properties of *Nandini* fruits, they (mass, length, breadth, size, surface area, sphericity and shrinkage) declined significantly during storage, in both storage conditions. The compressive force and energy decreased by 33.90 and 22.1%, and 24.52 and 18.33% in ambient and refrigerated storage condition respectively, whereas, the compressive strain decreased by 27.49 and 12.67% respectively in ambient and refrigerated conditions during storage. The compressive strain of the fruits in ambient condition was higher than refrigerated condition. The textural parameters (hardness and fracturability) decreased by 42.71 and 33.52%, and 56.18 and 43.21%, respectively for ambient and refrigerated, when the storage time was increased from 0 to 8 d. Therefore, it can be concluded that the investigated cultivar should be stored at lower temperature in other to minimize depreciation in the physical, mechanical and textural qualities, and maintain overall fruits quality. The information obtained from this study would to understand the effect of storage conditions on the changes in the physical, mechanical and textural quality of cucumber fruits. Therefore, the data would be useful in the design and development of optimal storage conditions for processing, packaging, transportation and storage systems for cucumber fruits for food and industrial use.

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