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Research Paper

Influence of Field Practices on the Performance of Cucumber Fruits harvesting and processing machines

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Effect of pre-harvest treatment on some mechanical properties of cucumber (cv. Nandini) fruits, which will affect its harvesting and processing machines, were investigated in this research. Cucumber plants were treated in the field with five treatments options, until cucumber fruits were harvested for laboratory analysis. The treatment used were; distill water, 100 mg/l $CaCl_2$, 200 mg/l $CaCl_2$, 100 mg/l $Ca(NO_3)_2$ and 200 mg/l $Ca(NO_3)_2$. The fruits were harvested at 15 Days after Peak Anthesis, and their compression parameters (failure force and failure energy) and shear parameters (shear force and resistance resistance) were tested according to ASTM International procedures. Results obtained revealed that pre-harvest treatment had significant ($p \leq 0.05$) effect on the failure force, failure energy and shear force of the cucumber fruits. All the mechanical parameters evaluated in the study, increased with the pre-harvest treatment. The study further revealed that the fruits treated with $Ca(NO_3)_2$, had superior mechanical properties than the fruits treated with $CaCl_2$. The failure force increased by 4.21% and 9.36%, as the fruits were treated with 100 mg/l $CaCl_2$ and 200 mg/l $CaCl_2$ respectively. Likewise, the cucumber failure energy increased by 6.11% and 11.09% at the treatment of 100 mg/l $CaCl_2$ and 200 mg/l $CaCl_2$ respectively. At the concentration of 100 mg/l $Ca(NO_3)_2$, the fruits recorded 6.38% and 9.93% increment in their failure force and failure energy respectively. Likewise, at a concentration of 200 mg/l $Ca(NO_3)_2$, the fruits failure force and failure energy increased by 12.37% and 17.34% respectively. Regarding the shear parameters, the control fruits recorded the least shear force (126. 64 N) and shear resistance (0.045 N/mm^2); while those fruits treated with 200 mg/l $Ca(NO_3)_2$ had the highest shear force and shear resistance of 170. 60 N and 0.051 N/mm^2 respectively. This study had shown the relevance of the knowledge of field practices, on the design and application of crops harvesting and processing machines. Results obtained from this study will be helpful in the design and optimization of cucumber harvesting and processing machines.

Keywords: Cucumber, compression test, field practices, Nandini, shear test

INTRODUCTION

Cucumber (*Cucumis sativus* L.) belonging to the *Cucurbitaceae* family, is widely cultivated across many parts of Nigeria. Cucumber fruit is rich in vitamins, minerals and essential amino acids (Ullah *et al*., 2012); and contains about 96% of water Mousavizadeh *et al*. (2010). Apart from its nutritional values, cucumber fruit still has a lot of pharmaceutical values. It contained essential antioxidant, antimicrobial, antidiabetic, and hypolipidemic compounds (Nema *et al.,* 2011; Nyorere and Uguru, 2018). According to Dhall *et al*. (2012), cucumber fruit is highly susceptible to shriveling at high temperature and chilling injury at very low temperature (≤10°C). Cucumber fruit is fragile and can be easily bruised or damaged through improper handling; making it susceptible to microbe infections and deterioration, which will lead to unacceptable market quality (Mikal, 2010). Due to the fragile nature of cucumber plants and fruits, its production is highly labour intensive.

Agricultural labour is a crucial limitation is food production, couple with the diminishing human population that is willing to engage in agricultural production (Hayashi *et al*. 2002). Numerous agricultural machines and equipment have been designed and developed, through the knowledge of the engineering properties of the agricultural materials. Automated cucumber harvesting, handling and packaging robots have being design and development by robotics scientists, using the optical and mechanical properties of a cucumber fruit. Anyanwu *et al*. (2018) designed, constructed and tested a fluted pumpkin leaves chopping machine, using the tensile and shear properties of the leaves. They observed that the machines had an efficiency of 73.2%. Bontsema *et al*. (2001) design and development an automated cucumber fruits harvesting system, with an efficiency of 75%, using the physical characteristics and mechanical properties of the cucumber fruit. A mechanical harvester for pickling cucumbers was designed and constructed by Oregon State University (OSU); the efficiency of the harvester was about 80%, when tested during various planting seasons (OSU, 1990). Mechanical harvesting and processing of agricultural products are more efficient, safer and hygienic, when compared with manual harvesting methods.

Physico-mechanical properties of agricultural products are vital factors to be considered during the design, construction and optimization of agricultural machines and equipment (Sirismoboon *et al*., 2007). The size, weight and density of agricultural products, are necessary during the design and application of sorting and grading machines. Rupture parameters of agricultural products are vital for the design and development of their milling/crushing machines; while shear and tensile parameters are essential for the design and programming of chopping/shearing machines. Furthermore, failure (bio-yield) properties of agricultural products are necessary for the development of their harvesting machine (Mousavizadeh *et al*., 2010). Failure parameters determine the efficiency of the harvesting, handling and packaging machines; considering the rate of mechanical damaged done to the products, by the machine. Experimental researches have it that, agricultural products with internal/external mechanical damage cannot stored well; thereby, lowering their storability and marketability (Pérez-Vicente *et al*., 2002). Recently, several researches have been done, on how to improve and maintain the physico-mechanical properties and storability of agricultural products. One of these studies is the application of calcium-based amendment, to improve the mechanical properties of agricultural products. According to Hepler and Winship (2010), calcium which is one of the macronutrients required by plants, helps in crucial development in plants which leads to structural rigidity of the plant's cell wall. It had being observed that the sclerenchyma thickness which is influenced by calcium, greatly affect the mechanical properties of plant's tissues (Zhong *et al*., 2002). Helper (2005) reported that calcium plays an essential part in the function and behaviour of plant's cellular structures. Zhao *et al*. (2008) stated that calcium helps in regulating the expansion of cells walls, mostly in cucumber plants.

According to Haq and Rab (2012), calcium chloride foliar application increased strength and cracking resistance of litchi (*Litchi chinensis* Sonn) fruits. Kirmani *et al*. (2013) reported that plum (*Prunus salicina* L.) fruits pre-harvest treated with calcium chloride had higher skin firmness (4. 67 kg/cm^3), when compared with the control (untreated) fruits (4.40 kg/cm^3). Likewise, Gayed et al. (2017) observed that peach (*Prunus persica* (L.) Batsch) fruits treated with 2% calcium chloride solution, recorded higher firmness and storability, compared to the control peach fruits. An increment in firmness and other physical characteristics of apple fruits were observed after pre-harvest treatment of the fruits with calcium solution (Salehi *et al*., 2013). Sharma and Pratima (2018) investigated the effect of calcium chloride and calcium nitrate, on the strength properties of peach fruits; they reported both the pre-harvest treatment significantly ($p \leq 0.05$) increased the firmness of the peach fruits.

The alterations observed in the physico-mechanical properties of pre-harvest treated agricultural products, will definitely affect the programming and application of their harvesting, handling and processing machines. Therefore, the knowledge of the physical characteristics and mechanical properties of pre-harvest treated agricultural products is necessary. Although several works have being done on mechanical properties of pre-harvest treated fruits and vegetables, using calcium chloride and calcium nitrate. There is scanty recorded literature on the effect of pre-harvest treatments, on the mechanical properties of Nigeria grown cucumber fruits. Therefore, the aim of this study was to evaluate the effects of calcium chloride ($CaCl_2$) and calcium nitrate ($Ca(NO_3)_2$), on cucumber (cv. Nandini) fruit development and its mechanical properties. The results will be helpful in the programming and optimization of Nigeria grown cucumber fruits harvester.

MATERIALS AND METHODS

Materials

Cucumber seed

Nandini cucumber seeds, used for this study were procured from the seeds centre of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria.

Methods

Experimental design and cucumber cultivation

To investigate the effect of pre-harvest treatment on the mechanical properties of cucumber fruit, five treatments which were; T1 (1 L distil water, and was regarded as the control), T2 (100 mg/l $CaCl_2$), T3 (200 mg/l $CaCl_2$), T4 (100 mg/l $Ca(NO_3)_2$) and T5 (200 mg/l $Ca(NO_3)_2$) were considered. Experimental plots measuring 3 m x 4 m, were prepared manually, and the cucumber seeds were planted at a spacing of 40 cm by 50 cm. Each treatment was carried out on three replications. The treatments were applied on the cucumber plant using a knapsack sprayer, twice weekly. The treatments application started from two weeks after germination of the cucumber seeds, until when the fruits were harvested for laboratory tests. Weeding was done manually, which pests were controlled using systemic insecticide (Dimethoate 40EC), applied at the rate of 1 L/ha.

Sample collection and preparation

At the flowering stage of the cucumber plants, the flowers were coded according to their anthesis date. All the fruits were closely monitored until they were harvested for the laboratory tests. The fruits used for this study were harvested at 15 Days after Peak Anthesis (DAPA). After harvest, the fruits were inspected manually, to remove all damage or pests infested fruits. The selected from were taken immediately to the laboratory for mechanical tests.

Compression test

The Universal Testing Machine (Testometric model) equipped with a 500 N compression load, was used to determine the compression properties of the cucumber fruit. During the test, the cucumber fruit was placed between the two compression cells, as shown in (Figure 1). A compression speed of 25 mm/min (ASAE S368.2) was used for the compression loading, which continued until the fruit ruptured. A load-deformation curve was plotted electronically by the machine in response of the fruit to the loading force. Two major points were captured during the loading process; which were the failure point and the rupture point. According to Mohsenin (1986), failure point of an agricultural material is the point after which an increment in the deformation could be observed, without any increased in the loading force. From the force – deformation results mined electronically by the machine, the cucumber failure parameters were calculated and displayed on the screen attached to the machine.

Shear test

The modified Warnere Bratzler device was used to determine the shear properties of the cucumber fruit. The device (1 mm thick 30° V-notch stainless steel sharp edge knife) was attached to the Universal Testing Machine (Testometric model). To test for the shear properties, the cucumber fruit was placed inside the support block (Figure 2), and machine cut the fruit into two parts, with the aid of the knife at a speed of 2 mm/min. During the loading process, the machine plotted a force-deformation curve, in responds of the fruit to the shearing force. The cucumber fruit shear's stress was calculated by using Equation 1. The test was conducted on twenty (20) cucumber fruits from each treatment plot.

$$S_s = \frac{S_f}{A} \quad (1)$$

Where:
S_s = shear stress
S_f = shear force
A = cut sectional area of the vine

Statistical analysis

All the Data obtained from this study will be analyzed using SPSS V. 20.0 (SPSS Inc., Chicago, USA). The means will be separated and compared by using the Duncan's multiple range tests (DMET) at 95% confidence level.

RESULTS AND DISCUSSION

Compression properties

Failure parameters were considered in this study, because the aim of the research was to obtain data for the design, construction, programming and application of cucumber harvesting, handling and packaging machines/systems. Failure point is a key factor to be considered during the application of these machines, to avoid food wastage during storage. According to Steffe (1996), failure point (also expressed as bioyield point) is the point of microstructural failure of a material, and it is associated with an internal disruption of cellular structure.

The ANOVA results given in (Table 1) showed that, treatment options applied had significantly ($p \leq 0.05$) effect the failure force and failure energy of the cucumber fruits. The separated means presented in (Table 1), revealed that the failure force and failure energy of the cucumber fruits, increased linearly with an increment of the treatment concentration. Fruits treated with 200 mg/l $Ca(NO_3)2$ had the highest failure force (844.23 N) and failure energy (6.69 Nm); while the control fruits had the lowest failure force (739.75 N) and failure energy (5.53 Nm). As shown in (Table 2), out of all the treatment options, the highest failure force and failure energy was recorded with the fruits with $Ca(NO_3)_2$ application. The fruits with $CaCl_2$ applications recorded the lower failure force and failure energy values, but higher than the failure force and failure energy values recorded in the

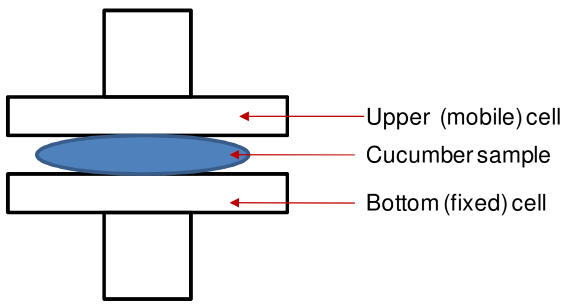

Figure 1: Schematic diagram of the cucumber fruit undergoing compression test.

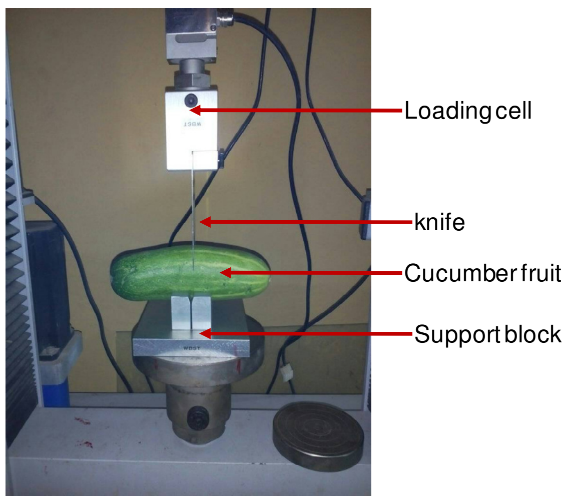

Figure 2: A cucumber fruit undergoing shear test.

control fruits. The mean fruit failure force and energy recorded in T2 (100 mg/l $CaCl_2$) fruits were 772.27 N and 5.89 Nm respectively; while the T3 (200 mg/l $CaCl_2$) fruits recorded an average failure force of 816.15 N and failure energy of 6.22 Nm individually. The superior failure force and failure energy values, recorded by the T4 and T5 fruits, may be due to the nitrogen content in the treatment. According to Fallahi (1997), nitrogen based soil amendment usually results in improved fruit development due to enhanced assimilation metabolism.

Although, the treatment applied exhibited significant ($p \leq 0.05$) effect on the failure properties of the cucumber fruits; the fruits harvested from T2, T3 and T4 did not exhibit ant significant difference in their failure force. Likewise, cucumber fruits harvested from T3 and T4 plots did not showed any significant ($p \leq 0.05$) difference in their failure energy (Table 2). The higher failure parameters values, recorded in the pre-harvest treated cucumber fruits, could be attributed to the calcium content present in all the treatment options. According to Serrano *et al.* (2004), pre-harvest treatment of crops with calcium-based solution results to increment in their tissues calcium content. This eventually led to their improved mechanical properties. Conway and Sams (1984) stated that calcium plays a crucial part maintaining cellular structures, by collaboration with pectic acid within the cells to produce calcium pectate. This study had revealed that the force exerted on cucumber fruit during mechanical harvesting, is dependent on the pre-harvest treatment applied on the plant. In addition, it can be seen from the results that pre-harvest treatment, will reduce of mechanical damages during the process of mechanized harvesting of the fruits. Mechanical damages that occurred fruits and vegetables during mechanical harvesting operations, usually led to about 30% food wastage (Shahedy, 2007); therefore, developing systems that will minimized this food wastage have become inevitable.

Shear properties

The ANOVA results presented in (Table 2), showed that treatment had significant ($p \leq 0.05$) effect on the shear force; but did not exhibit significant ($p \leq 0.05$) effect on the shear resistance of the cucumber fruit. Regardless of the treatment, shear properties increased linearly, with increase in the treatment concentrations (Figures 3 and 4). As presented in (Figure 3) and (Figure 4), the control fruits exercised the lowest shear force (126. 64 N) and shear resistance (0.045 N/mm^2); while the fruits treated with 200 mg/l $Ca(NO_3)_2$ exercised the maximum shear force (170. 60 N) shear resistance (0.051 N/mm^2). The shear force and shear resistance of cucumber fruits treated with 100 mg/l $CaCl_2$ increased by 12.19% and 2.17% respectively. Likewise, the shear force and shear resistance of cucumber fruits treated with 200 mg/l $CaCl_2$ increased by 19.55% and 8.16% respectively. The foliar application of $Ca(NO_3)_2$ at the rate of 100 mg/l increased the shear force of the cucumber fruits by 16.00%, and the shear resistance by 6.25%. Similarly, it was observed that the foliar application of $Ca(NO_3)_2$ at the rate of 200 mg/l increased the shear force of the cucumber fruits by 25.76%, and the shear resistance by 11.76%.

It can be seen than the fruits treated with $CaCl_2$ generally required lower force to shear, when compared with the fruits treated with $Ca(NO_3)_2$. This portrayed that nitrate content played significant role in the cellular structure development, apart from the major role played by the calcium concentration. Zahirul *et al.* (2018) observed that nitrate had a higher potential of increasing plant's tissue firmness and rigidity, when compared to chloride, during pre-harvest treatment. Shear properties are manually considered as vital factors during the slicing and chopping of cucumber fruits, as they determined the amount of force to be applied by the knife/machine on the fruit. These results on the shear properties will be useful in the design and optimization of cucumber fruits processing machines.

Table 1: Mechanical properties of cucumber fruit in compression test

Treatment	Failure force	Failure energy
T1	$739.75^{a}\pm86.85$	$5.53^{a}\pm0.61$
T2	$772.27^{ab}\pm86.44$	$5.89^{a}\pm0.58$
T3	$816.16^{ab}\pm79.89$	$6.22^{ab}\pm1.04$
T4	$790.24^{ab}\pm78.19$	$6.14^{ab}\pm0.90$
T5	$844.24^{b}\pm78.01$	$6.69^{b}\pm0.69$
Mean	**792.53**	**6.09**
DMRT (p ≤0.05)	*	*

Mean± standard deviation; n=20; mean separation within columns by Duncan's multiple range tests (DMRT); * significant at p ≤ 0.05.

Table 2: ANOVA table of the mechanical properties of cucumber fruit in shear test

Dependent variable	df	F Stat	Sig
Shear force	4	6.9242	6.77E-04*
Shear resistance	4	0.9938	0.4292^{ns}

* = significant at p ≤ 0.05; ns = non-significant at p ≤ 0.05.

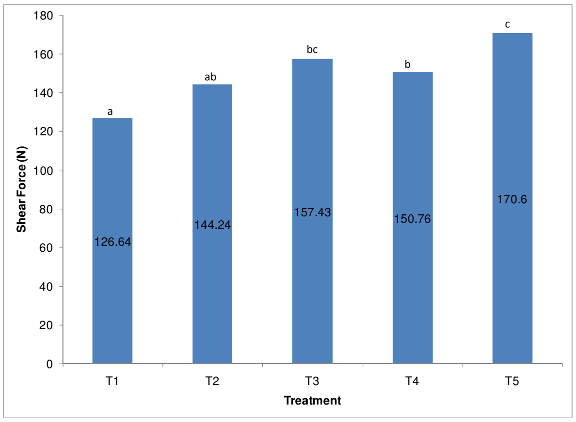

Figure 3: The shear force of cucumber (cv. Nandini) fruit.
Bars with the same superscript common letter are not significantly different (p ≤0.05), according to DMRT.

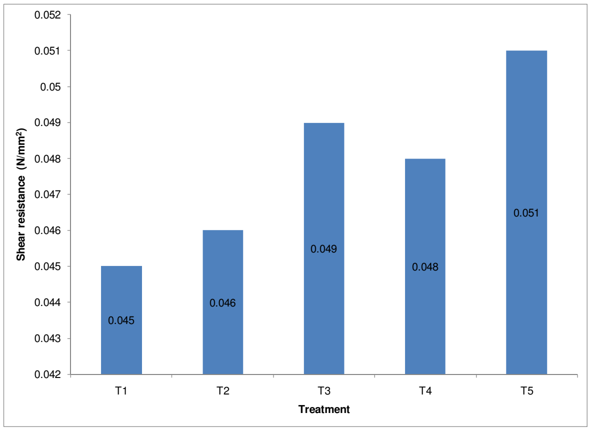

Figure 4: The shear resistance of cucumber (cv. Nandini) fruit.

Conclusion

Effect of calcium chloride and calcium nitrate pre-harvest treatment on the mechanical properties of cucumber (cv. Nandini) fruits was examined in this study. The cucumber fruits were harvested at 15 DAPA, and their mechanical properties (failure force, failure energy, shear force and shear resistance), tested according to ASTM International standards. The results obtained from the mechanical tests showed that, calcium chloride and calcium nitrate had significant effect on the failure force, failure energy and shear force of the cucumber fruit. The control fruits recorded the lowest mechanical properties; while the fruits treated with 200 mg/l $Ca(NO_3)_2$ had the maximum mechanical properties. The compression and shear parameters of the cucumber fruits treated with calcium nitrate were higher than those of the treated with calcium chloride. It was also observed that, all the parameters investigated increased with an increment in the treatments concentrations. The fruits treated with 100 mg/l $CaCl_2$ had failure force, failure energy, shear force and shear resistance of 772.27 N, 5.89 Nm, 144.24 N and 0.046 N/mm^2 respectively. While fruits treated with 200 mg/l $CaCl_2$ recorded failure force, failure energy, shear force and shear resistance of 816.16 N, 6.22 Nm, 157.43 N and 0.049 N/mm^2 respectively. The results obtained from all the parameters evaluated, are essential for the design and development of cucumber fruits harvesting and processing machines/automated systems.

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