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COMPRESSION DAMAGE THRESHOLD OF YOUNG COCONUT (*Cocos nucifera L.*) AT TWO MATURITY STAGES

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Abstract:
Information on the damage incidence of young coconut was generated by establishing the threshold values due to compression. Factors influencing damage and deformation under dead load were evaluated. It was found that maturity, time of load application and load significantly affected bruise area and deformation of young coconut. Larger bruise area was noted for 6-7 month old (Mat1) nuts as compared with 7-8 month old (Mat2) nuts. On the contrary, Mat2 had significantly higher deformation than Mat1. It was found that Mat1 nut was firmer and stiffer than Mat2 nuts. Fruits at both maturity levels can only resist 75-kilograms dead load at 3 hours loading without significantly causing any detectable damage over the fruit's surfaces. Generally, increase in the magnitude of bruise area and deformation was associated with the increase in load and time of load application. Correlation analysis revealed that bruise area and deformation were significantly correlated with load. Some positive correlations were also found to exist between bruise and time of loading. Prediction models were developed and validated for compression relating magnitude of bruise and deformation on different parameters in the study.

Keywords: *Maturity Stage; Deformation; Young Coconut; Creep-Recovery.*

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1. Introduction

The study of Gatchalian (1992) categorized maturity of the nut into different stages or age levels, the amount of meat and its tenderness determines whether the nut is used as a food or as beverage (as cited in Pascua, 2017). At the 6-7 month old or locally known as malauhog is a mucus-like stage when the meat is very soft and jelly-like. The 7-8 month old fruit or locally termed as malakanin is a cooked rice-like stage. The volume of water decreases, while the meat changes from jelly-like to a firm opaque-white solid mass. The meat at this stage is used as pie filling or salad. At 8-9 months maturity level is a leather-like coconut meat or locally known as malakatad, the meat is very much firmer. Quintos 1991 noted that at this stage of maturity, the meat can only be utilized for cooked sweetened deserts or as bread fillings.

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Compression testing of intact biological materials provides an objective method for determining mechanical properties significant in quality evaluation and control, maximum allowable load for minimizing mechanical damage, and maximum energy requirements for size reduction (ASAE, 1988). Shigley and Mitchell (1983) noted that compression tests are more difficult to perform than tension tests for most materials since specimens may buckle during testing and stresses are not evenly distributed.

Tongdee et al. (1991) investigated the rupture force (the force that initiates tissue failure) of young coconut at different maturity stages using a Universal Instron Testing Machine. Fruits for rupture force measurement were trimmed to remove all outer fibrous tissues before testing. Results showed that there was a significant increase in rupture force as the maturity of the fruit advanced. Moreover, the rupture force of a commercially acceptable tender coconut having a desirable endosperm texture ranged between 97 and 182 kilograms.

Extensive studies had been done in determining the compressive properties, but mostly for pears, apples, potatoes, tomatoes and water melon. Fridley et al. (1966) observed that bruising in compressed peaches occurred when contact stress reached 0.41-0.43 Mpa. In addition to the studies of the bruising of peaches, bruising studies of other fruits, particularly apples and potatoes, provide some insight into bruising effects (Burton et al., 1987; Siyami et al., 1987; Garcia et al., 1988). Links between laboratory studies and commercial practice have been established by studies monitoring the occurrence of bruises on produce moving through postharvest operations (Burton et al., 1987; Brown et al., 1990). Li and Thomas (2017) stated that compression damage occurs as result when packing products forcibly into a small container. It was recommended that fruits such as melon should be packed firmly and tightly to avoid chafing and to avoid their curved surfaces to become flattened. Mechanical damage to tomato fruits was also a result of the extent of compression, the curvature of the finger surfaces and internal structural characteristics (Li, 2013; Li, Li, & Liu, 2010; Li, Li, & Yang, 2013; Li, Li, Yang, & Liu, 2013) as cited in Li and Thomas (20_). Susceptibility of packaged fruits to damage increases by compression loading with increase in fruit ripeness and vibration levels. The said factors are inter-related which determine the intensity of compression damage inflicted on packaged fruits.

Mohsenin (1980) stated that because of the time element combined with dead loads involved in bulk handling, the mechanics of the force-deformation relationship is usually a creep phenomenon. In an attempt to derive readily used relationships applicable to practical situations, Nelson (1967) investigated the dead load required over a period of time to cause undesirable distortion or internal browning in McIntosh apples (as cited in Mohsenin, 1980). Fruits were subjected to dead loads for a period of 24 hours at 32ºC and 100 hours at 4.4ºC. Results of the study produced regression equations for predicting bruise volume or surface distortion from the applied force or pressure.

Young coconut is subjected to excessive impact stress as result of improper harvesting and handling practices (Pascua, 2017). Yahia (2015) stated that if the fruits are not carefully handled during harvesting, browning of the white husk under the outer skin will be evident as result of bruising, It was pointed out that sulfite treatment after peeling cannot remove the bruised appearance. External bruising occurs during temporary storage of fruits. Figure 1 shows

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a typical practice for holding young coconut before trimming and marketing. Fruits at the bottom layers are subjected to severe compression that can cause damage. Pascua (2017) noted that bruises on young coconut are not visible immediately after impact, but appear only after enzymatic browning in the injured tissue has occurred. Consumers are very particular on the quality of the fruit and appearance of even a small bruise will affect its market.

Therefore, it is very important to consider the factors influencing these damages due to compression stress on young coconut so that problems in handling will be better understood and recommendations can be made. The aim of this study is to measure the severity of damage on young coconut by establishing the threshold values for compression.

Figure 1: Typical practice for holding young coconut

2. Materials and Methods

Laguna Tall coconut variety at two stages of maturity was used for the study. Sample nuts harvested 6-7 months after flowering (with mucus-like consistency of the endosperm) herein referred to as Mat1 nuts and samples harvested 7-8 months after flowering (with cooked rice-like consistency) was referred to as Mat2 nuts. These levels of maturity were objectively determined by taking representative samples from source trees before harvesting. This ensured that samples used in the study were taken only from those bunches with the required maturity.

Creep test was done to determine the extent of damage of young coconut under dead load. A simple creep apparatus, similar to that utilized by Nelson (1967) was used to simulate actual stacking condition of young coconut under a rhombic arrangement, assuming that the fruits are cylindrical in shape. The set-up consisted of a rectangular base platform and a triangular box made from 6.35 mm thick steel plates. A "Mitutoyo" dial-type displacement indicator (accurate to 0.01 mm) mounted on the base was used to monitor deformation. The triangular box served as a container for sand and served as the dead load. Two complete apparatus were fabricated to be able to analyze two treatments at a time (3 nuts per treatment).

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Three main factors were considered in the study namely: maturity, time of load application, and dead load. Dead loads of 75, 125, 175, 200, and 225 kg were applied for 3, 6 and 9 hours for each maturity. Prior to the test, weight and equatorial diameter of the samples were measured. These were used in establishing predicting equations for damage under dead load. Three (3) samples were arranged on the base platform in a triangular manner. A 38.1 mm thick styrofoam sheet was placed on top of the samples to determine the initial reading of the dial at zero deformation. This was done so that the tip of the gage would be at the same level as the top of the samples. After setting the dial at the zero reading, the styrofoam sheet was removed and the triangular steel box loaded with sand at a specified weight was then placed on top of the samples. An electric chain hoist was used for lifting and lowering loads over the samples. Loading time started just after placing the load, taking note of the initial deformation at time zero. Monitoring and recording of deformation was done every 30 minutes. After the specified loading time, the load was removed and replaced with the styrofoam sheet for monitoring recovery. Recovery was also monitored and recorded every 30 minutes. Recording stopped when no more changes were observed on the reading of the dial meter. The final reading was noted to be the average permanent deformation of the three samples in the setup. Samples subjected to a specified load were left for 24 hours under ambient conditions to allow full development of the bruise.

Dimensions of the contact area at the top and bottom surfaces of each sample were directly measured since the compression plate laid an outline of contact at the deformed surface after the load was removed. The shape of contact and bruised portion exhibited that of an ellipse. A prediction model of bruise area was validated by conducting the same test procedures using 75, 175 and 225 kilogram loads for 3 and 6 hours loading duration. Actual bruise area of samples were obtained and compared with the predicted values based on the models. After recording deformations with time, creep and recovery curves were constructed for each treatment where data such as instantaneous elasticity, retarded elasticity, and permanent deformation were obtained.

The study was conducted using a 2 x 5 x 3 factorial (2 levels of maturity by 5 levels of load by 3 levels of time of application) experiment. Analysis of variance (ANOVA) was conducted using completely randomized design (CRD) at 5% level of significance. Correlation and regression analysis was also performed to determine the relationship of the dependent and independent variables and to establish prediction models for damages.

3. Results and Discussions

3.1. Effect of Maturity, Time of Load Application and Load on Bruise Area

The results proved that area of bruise is associated with the maturity of young coconut. Larger bruise area was noted for the less mature stage (M1) compared with the more mature stage (M2). Results revealed that mean bruise areas for the time of load application were significantly different from each other for the top surface. For bottom surface, the mean bruise area for 3 hours loading was significantly different from mean bruise areas for 6 hours and 9 hours, respectively. However, the mean bruise areas for 6 hours and 9 hours were found to be not significantly different from each other for bottom surface. Generally, the findings suggest that

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increasing the load and time of load application had significant increase on the magnitude of bruise area at 5% level of confidence as shown in Figures 2 and 3; respectively for both surfaces.

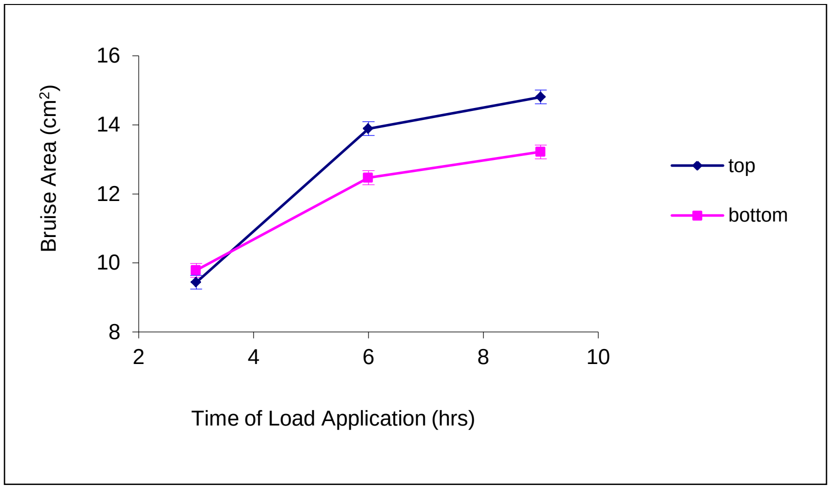

Figure 2: Effect of time of load application on bruise area

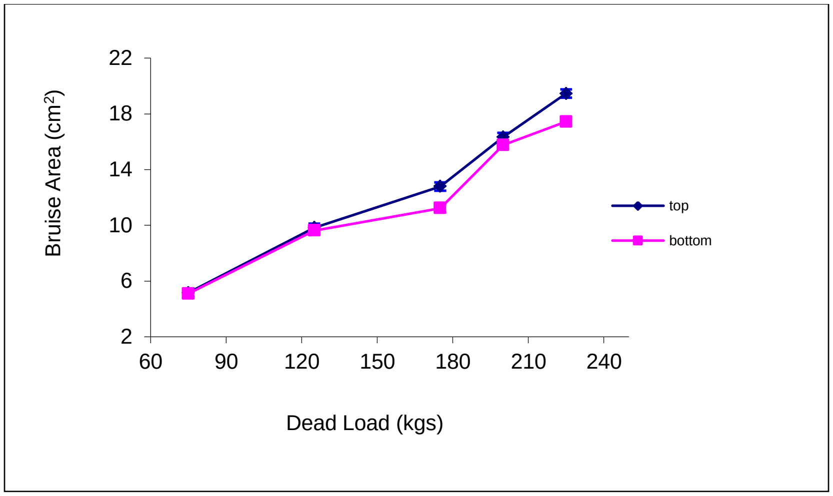

Figure 3: Effect of dead load on bruise area

Results of DMRT revealed that mean bruise areas of the different levels of load significantly differ from each other for the top and bottom surfaces. This result implies that load greatly influenced the magnitude of bruise area. As the level of load increased, surface area of bruise also increased. Generally, Mat1 had the higher bruise area as compared with Mat2 nuts. Hence, Mat2 was more resistant to bruising than Mat1 at the same load application.

Regardless of maturity, it was observed that young coconut could only resist 75 kilograms load for 3 hours loading without significantly causing any detectable damage on fruit surfaces incontact. It was noted that time of load application had a significant effect on the magnitude of bruise area given the same reference load. Bruise area was higher when load was applied at a longer duration.

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It was observed that bruise area was significantly lower under the lowest level combinations of load and time of application. In general, higher levels of load and time of loading determine magnitude of bruise. However, It can be noticed based from the results that load and time of load application had caused significant influence on the magnitude of bruise on the bottom surface. This fact implies that bottom surface is more susceptible to bruising at higher compressive stress. Hence, it is recommended that young coconut must not be stacked so high so that occurrence or development of surface bruises at the bottom layer of stack will be prevented.

Table 1: DMRT of mean bottom surface bruise area (cm^2) of the interaction between load and time of load application

Time, Hours	Load, Kilograms				
	75	125	175	200	225
3	0.00	8.32 ^{i}	10.18 ^{h}	12.36 ^{g}	16.33 ^{d}
6	7.37 ^{j}	10.54 ^{h}	14.78 ^{e}	17.29 ^{c}	19.45 ^{b}
9	8.10 ^{ij}	10.65 ^{h}	13.40 ^{f}	19.32 ^{b}	22.60 ^{a}

* Means with the same letter(s) are not significantly different by DMRT at the 5% level of significance.

Table 2: DMRT of mean top surface bruise area (cm^2) of the interaction between load and time of load application

Time, Hours	Load, Kilograms				
	75	125	175	200	225
3	0.00	9.05 ^{fg}	9.84 ^{ef}	13.54 ^{g}	16.52 ^{bc}
6	6.83 ^{h}	9.59 ^{ef}	13.07 ^{d}	17.65 ^{b}	18.95 ^{a}
9	8.44 ^{g}	10.22 ^{ef}	10.78 ^{e}	16.08 ^{c}	16.83 ^{bc}

* Means with the same letter are not significantly different by DMRT at 5% level of significance.

3.2. Effect of Maturity, Time of Load Application and Load on Deformation

Though only slight difference was observed for mean deformations of Mat1 and Mat2 nuts, but was found to be significant using DMRT. Mat2nutswere significantly higher thanMat1 nuts in terms of surface deformation due to compression stress. The result must be associated with the firmness of husk at these stages. Pascua (2017) reported that Mat1 nut had a mean firmness of 251.67 N (25.65 kgs) and M2 nut had a mean of 237.34 N(24.19 kgs). It was proved that husk of Mat1 is firmer than that of Mat2. Firmness might also be related with the moisture content (MC) or air spaces within the husk at these stages. Husk of Mat1 nut had higher MC hence, had less air spaces than Mat2 nut. This showed that Mat1 was more resistant to deformation under dead load than Mat2 nuts.

The DMRT of mean deformation at different levels of time of load application revealed that mean deformations for 3, 6, and 9 hours were significantly different from each other. Nine hours loading had the highest deformation while least was noted for 3 hours. These results imply that the magnitude of deformation on the husk is affected by the time of load application. The longer

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the time load is applied, the greater is the deformation. The effect of load was also observed to be highly significant on the magnitude of deformation. Results of DMRT reveal that the means of the different loads were significantly different from each other at $\alpha = 0.05$. Higher deformation was noted for heavier loads. The highest mean deformation was recorded for 225 kgs and lowest for 75 kilogram. Generally, as load increased the magnitude of deformation also increased. Figures4 and 5 show increasing trends of deformation with load and time of load application.

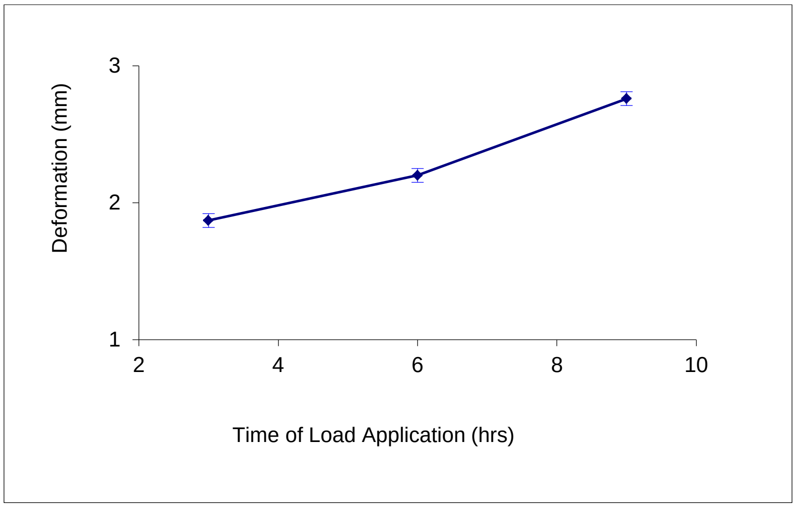

Figure 4: Effect of loading time on deformation

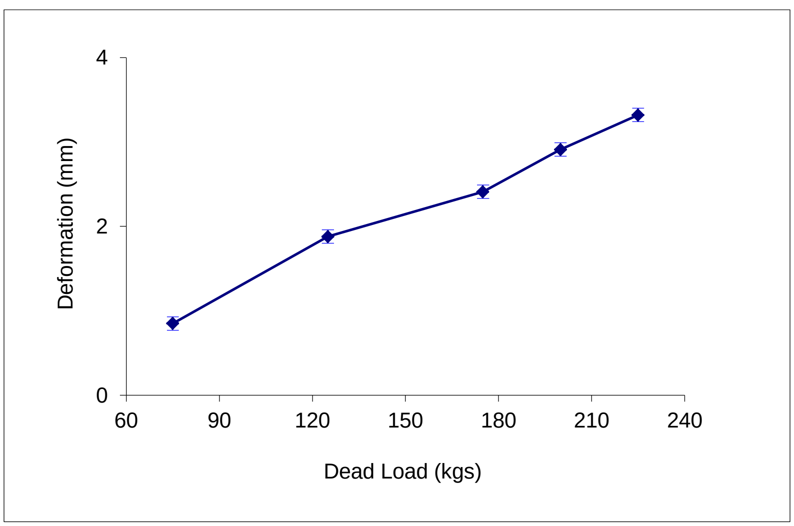

Figure 5: Effect of load on deformation

3.3. Effect of Maturity, Time of Load Application and Load on Modulus of Elasticity, Instantaneous Elasticity, and Retarded Elasticity

Figure 6 is the creep and recovery curve for young coconut at M2 stage under dead load for 6 hours. The curves exhibited instantaneous elasticity (E_o), retarded elasticity (E_r), and viscous flow (v). It can be observed that at lower load (75 kgs), the curve approximates that of a typical creep and recovery curve where instantaneous deformation (strain) is equal to the deformation at

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the recovery part. However at higher loads, initial deformations were noted to be higher than that of the recovery part of the curve.

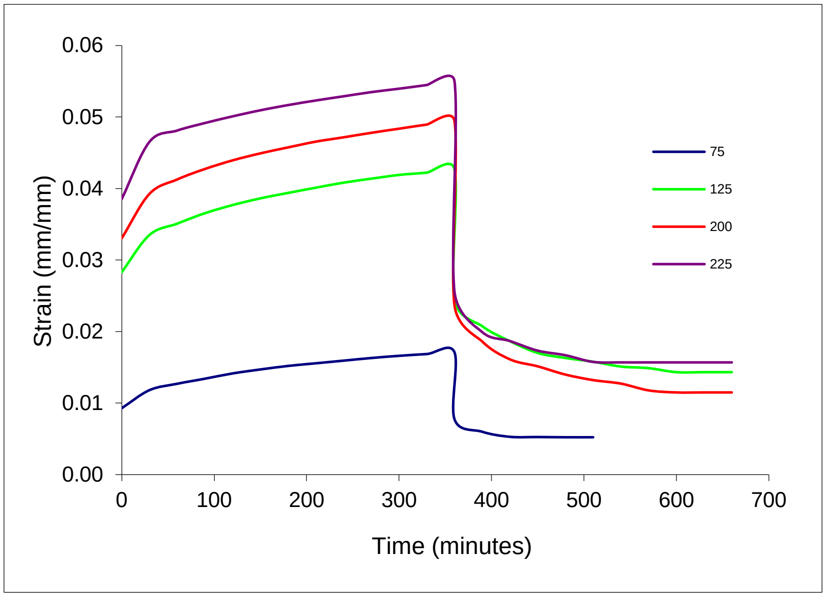

Figure 6: Creep and recovery curves for young coconut

Differences of the two levels of maturity under different loads and time of load application in terms of modulus of elasticity, instantaneous elasticity, and retarded elasticity were determined. Analysis of variance revealed that the simple effects of maturity, time of load application, and load; and their interactions were significant at 5% confidence level. Results show that Mat1 and Mat2 were significantly different from each other in terms of modulus of elasticity (*Y*), instantaneous elasticity (E_o), and retarded elasticity (E_o). It was noted that M1 nut was significantly higher than M2 nut. In terms of *Y*, the results imply that Mat1 was stiffer than Mat2 nut. This finding is somehow related with the study of Curada *et al.* (2001) where claimed that modulus of elasticity decreased with fruit maturity.

Correlation analysis (Table 3) for each level of maturity was done to determine relationship of bruise area and deformation with the different parameters at the same time correlation was tested between parameters. For Mat1, though time of loading was observed to have positive correlations with bruise area on both surfaces and deformation but not significant. Only load was established to have positive and highly significant correlations with bruise areas and deformation. On the other hand, only modulus of elasticity showed a negative but significant correlation with deformation. Relating the other parameters, instantaneous elasticity was noted to have strong positive correlations with modulus of elasticity and retarded elasticity. No correlation was established between time of loading and load and their relationship with other parameters. For Mat2, few correlations were noted that were significant. Only load was found to have strong positive correlations with bruise areas for the two surfaces and deformation. Some negative correlations were noted for Instantaneous elasticity, retarded elasticity, and modulus of elasticity on bruise area or deformation but were not significant. In general, no significant correlation was found to exist between the other parameters.

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Table 3: Correlation analysis between different parameters under two levels of maturity

Parameters	**Time**	**Load**	**Instantaneous**	**Retarded**	**Modulus**
Mat1					
Bruise (top)	0.368	0.884**	-0.341	-0.210	-0.334
Bruise (btom)	0.249	0.856**	-0.247	-0.144	-0.275
Deformation	0.388	0.904**	-0.470	-0.273	-0.543*
Instantaneous	-0.225	-0.415	1.000	0.840**	0.644**
Retarded	-0.446	-0.120	0.840**	1.000	0.320
Modulus	-0.131	-0.467	0.644**	0.320	1.000
Mat2					
Bruise (top)	0.411	0.860**	-0.263	-0.048	-0.199
Bruise (btom)	0.193	0.906**	-0.241	0.109	-0.105
Deformation	0.366	0.876**	-0.419	0.008	-0.297
Instantaneous	0.045	-0.431	1.000	0.417	0.817**
Retarded	-0.284	0.090	0.417	1.000	0.678**
Modulus	-0.254	-0.225	0.817**	0.678**	1.000

3.4. Relationship of Bruise Area and Deformation to the Different Parameters

Stepwise multiple regression analysis was done to determine relationships that maybe used in predicting the magnitude of bruise area and deformation for each level of maturity. All variables that were significant at $\alpha=0.10$ were included in the model.

Bruise area (top surface). For malauhog, top bruise area is determined by load applied, time of loading, and Modulus of elasticity ($BA_{top} = -10.737 + 0.106LA + 0.944TL + 0.00028ME$) with $r^2 = 0.939$. For malakanin, load applied and time of loading influenced top bruise area ($BA_{top} = -6.679 + 0.08582LA + 0.901TL$) with $r^2 = 0.909$. The inclusion of modulus of elasticity in the equation for M1 may be due to the reason that M1 is stiffer than M2 as previously claimed.

Bruise area (bottom surface). For malauhog, bottom bruise area is a function of load applied and time of loading ($BA_{btom} = -4.093 + 0.0833LA + 0.533TL$) with $r^2 = 0.795$. For malakanin, time of load application was eliminated from the equation may be due to the fact that load applied had greater influence in the magnitude of bruise area at the bottom surface than time of loading ($BA_{btom} = -1.120 + 0.07711LA$) with $r^2 = 0.821$.

Deformation For malauhog, deformation is determined by load applied and time of loading ($D = -1.462 + 0.01662LA + 0.157TL$) with $r^2 = 0.968$. For malakanin, deformation is also influenced by load applied and time of loading ($D = -0.848 + 0.01513LA + 0.140TL$) $r^2 = 0.903$.

Figures 7 and 8 present the graphs of actual and predicted bruise area based on the models for M1 and M2 nuts, respectively. Generally, the models underestimate actual bruise area for both surfaces and loading period. However, it can be observed that the models for Mat2 nuts had a closer prediction of actual bruise area than the models for Mat1 nuts.

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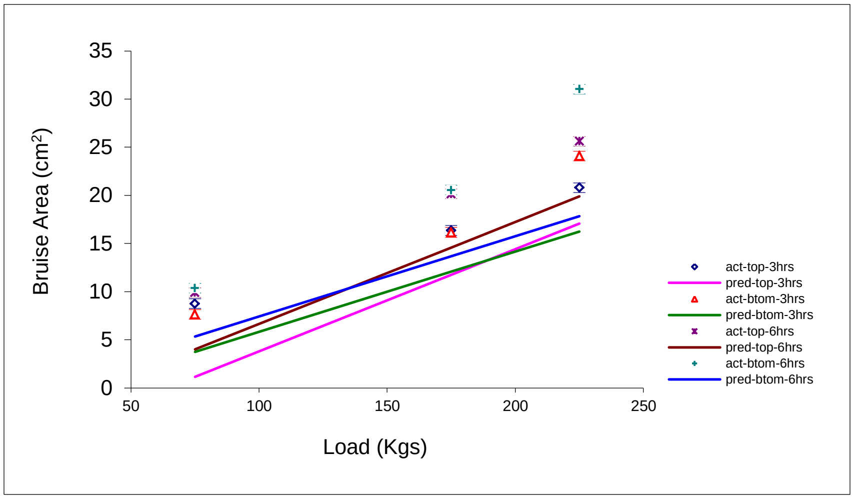

Figure 7: Plot of actual average bruise area and predicted bruise area based on the models for Mat1 nuts

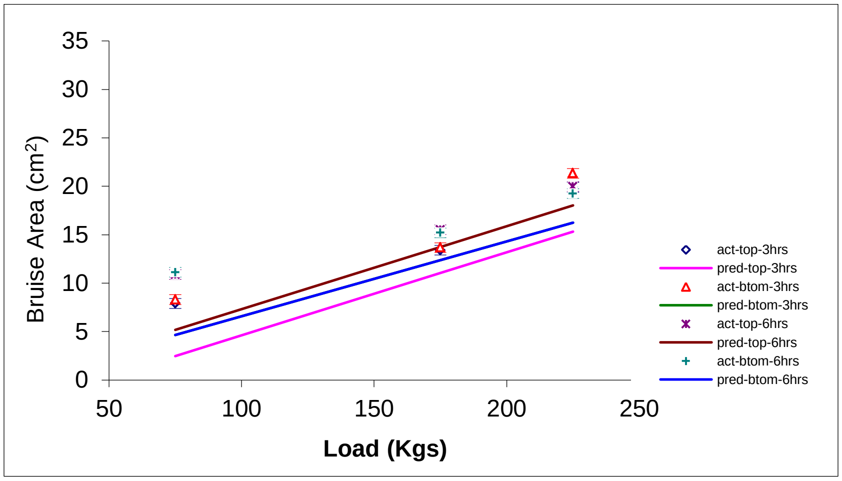

Figure 8: Plot of actual average bruise area and predicted bruise area based on the models for Mat2 nuts

No standard basis yet with regard to setting the allowable value of bruise area and deformation of young coconut under compressive load can be found despite enormous data available in literatures. However, with the data at hand and predicting equations developed, magnitude of bruise can be relate to its corresponding allowable depth of stack in actual stacking condition. The analysis was similar to that used by Nelson (1967) and Ross and Isaacs (1961) utilizing readily available equations (as cited in Mohsenin, 1980). This was done by first specifying a value for bruise area or deformation and look for its corresponding depth to limit its specified value.

All calculations were based on a $1m^3$ space, which can contain 167 pieces of young coconut and time of loading of 6 hours. The summary of maximum allowable depth to limit a surface area of bruise to 1 cm^2 is presented in Table 4. For Mat1, in order to limit bruise area at the top and bottom surfaces to the specified value, depth of stack should not be more than 234.19 cm and 113.90 cm, respectively. Similarly for Mat2, depth of stack should only be up to about 135.46

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cm or 140.61. On the other hand, Table 5 presents the summary of maximum allowable depth to limit a specified value of deformation. A depth of 800.73 cm is allowed to limit a deformation of 2.138 mm for Mat1, while only up to about 825.41 cm height is allowed to limit Mat2 nuts a deformation of 2.432 mm.

Table 4: Summary of maximum depth to limit bruise area of fruit surfaces to 1 cm^2 for both levels of maturity

Maturity	**Ave. Dia.(cm) ***	**Ave. Wt. (Kgs) ***	**Allow. Depth, cm**	
			Top	**Bottom**
Malauhog	16.36	2.38	234.19	113.90
Malakanin	16.83	2.53	135.46	140.61

* Actual average value

Table 5: Summary of maximum depth to limit the specified value of deformation

Maturity	**Deformation (mm)***	**Ave. Dia. (cm)***	**Ave. Wt. (Kgs)***	**Allow. Depth(cm)**
Malauhog	2.138	16.36	2.38	800.73
Malakanin	2.432	16.83	2.53	825.41

* Actual average value

4. Conclusions and Recommendations

Compression stress produced deformation and a form of bruising that differed from that produced by impact stress. Deformed surfaces can have an impact on the overall quality of the fruit, hence must be taken into consideration during handling. Bruise was evident on exocarp surface. This makes it different from impact bruise since bruising took the form of black discoloration, possibly due to cell disruption and consequent enzymatic reaction. The bruise was also similar to that of an ellipse. Like other forms of damage, the black spot bruise detracts from the overall appearance of the fruit that can affect its visual quality, thus making it more difficult to sell the fruits even in local markets.

It is recommended that young coconut must be stacked within the allowable time of load application and height of stack in order to avoid development of large bruises and deformation on the top and bottom surfaces of fruit due to compression stress. The fruits may be marketed immediately after harvest to take advantage of the quality that is free from any damage due to compression stress.

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