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Effect of Mechanical Damage on Tomato Fruits under Storage Conditions

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ABSTRACT

This research was carried out to study some mechanical damage effecting properties on tomatoes during storage. Experimental include simulation of mechanical damage by using a device developed by (Geasa, 2021). A device used to compress tomato's sample to achieve a 10 mm deformation distance. Two methods namely, flat probe and 30˚ cone penetration probe, two compress positions Z axis and X axis, and two storage methods (room and cooling conditions), under 4 storage periods (5, 10, 15 and 20 days) were tested. Physical properties (the mean length, width, thickness, arithmetic mean diameter, geometric mean diameter, surface area, sphericity, aspect ratio, mass, volume, and true density) of the tomato were 48.78, 56.48, 53.27, 52.84, 52.71mm, 8759.62 mm^2, 1.08 %, 1.16, 83.67 g, 87.85 cm^3, and 0.96 g/cm^3, respectively. Average temperatures C° were 18.8 and 9.9 and relative humidity % were 53.4 and 47.56 for room and refrigerator respectively. Mechanical properties of static friction coefficients for five surfaces of wood, plastic, rubber, cartoon, and galvanized iron steel were 0.4, 0.27, 0.33, 0.26 and 0.29 respectively. The changes in chemical properties of tomato including total soluble solids (TSS), and pH were measured. The study final results reveal that, the highest value of firmness of 2.8 N/cm^2 was obtained at refrigeration storage method and control sample. While, the average of force needed to made 10 mm deformation on z axis more than on x axis of tomato samples.

Keywords: Tomato chemical properties, Physical properties, Arduino, Storage methods

INTRODUCTION

Tomatoes are a significant crop for smallholder farmers in Egypt, both in terms of consumption and income. Egypt is the world's 6^{th} tomato grower. Several difficulties, as well as high levels of quantitative and qualitative losses, were observed across the value chain. The tomato value chain in Egypt is dominated by small-scale growers that use traditional growing methods on widely fragmented land plots. Tomatoes are produced on up to 80% of the land on plots of 5 feddans or less. (FAO,2021). Tomatoes are one of the crops that are most sensitive to mechanical and physical stresses. Mechanized equipment for harvesting, cleaning, sorting, grading, storing, and packaging tomatoes for transit from fields to processing factories or market regions must take into account the physical and mechanical characteristics of tomato fruits. Understanding the impacts of mechanical injury on tomato fruits can help to reduce decay during harvesting and processing.

Albaloushi *et al.* (2012) determined the mechanical properties such as dynamic coefficient of friction and mechanical properties namely firmness, hardness, resilience, fracturability, impact, bruising damage and total positive area in puncture test for tomato of the commercial variety. They added that these properties are necessary in the design of the equipment for harvesting, processing and transportation, separating and packing.

Mohsenin (1986) defined damage as the failure of a product due to excessive deformation when driven through a fixed clearance or excessive force when impacted. External forces under static or dynamic conditions, as well as interior forces, cause mechanical damage in agricultural products. Internal pressures can cause damage to fruits and vegetables, as well as grains, as a result of physical changes and exterior forces such as mechanical injuries. Arana (2012) reported that Impacts and shocks occur during the harvesting, transport, and manipulation procedures, resulting in mechanical damage. Damages might occur immediately following an impact or compression, or later during storage. As a result of these damages, the product's quality suffers and its sale price falls. He goes on to say that improving a food product's quality will boost its profitability and market reach. Arazuri *et al.* (2007) evaluated the behavior of tomatoes during transport by destructive compression test. When the container is full, tomatoes placed in the lower and middle portions of the container pars suffer a high compression force due to the weight of the tomatoes above them.

Desmet *et al.* (2002) built a pendulum to assess the sensitivity of two tomato cultivars to puncture injury as a function of storage duration and color stage. They found that: (i) tomatoes at harvest were less susceptible to puncture injury than after storage for several days; and (ii) colour at harvest had no effect on the susceptibility for puncture injury. They added that physicochemical characteristics are influenced by mechanical forces. Losses of citric acid and soluble solids, which increased the solid: acid ratio, that this ratio is ripening factor.

Jahanfar *et al.* (2011) studied the impact energy by a pendulum compress apparatus, on changes of physicochemical properties of tomato. They found that increasing mechanical energy tends to, shelf life, texture resistance decreasing. They added that increasing impact energy not only reduces firmness texture and wet content in production but also increasing ripening factor and its color during storing time.

Li *et al.* (2010) carried out the effect of mechanical damage on mass loss and water content in tomato they found that loading position had a gradual significant effect on mass loss during storage.

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Desmet *et al*.(2002) investigated the relation between mechanical properties of tomato and puncture injury susceptibility. A universal testing equipment and an acoustic firmness sensor were used to measure mechanical qualities. A pendulum test was used to assess puncture injury susceptibility. The mechanical qualities of the tomato cultivar and its puncture damage susceptibility were discovered through a relationship with a coefficient of determination. The force required to puncture a tomato with and without skin, the elasticity of the fruit, the toughness of the skin, and the acoustic stiffness of the tomato fruit all had high loadings, showing that these mechanical qualities influence puncture damage susceptibility.

Mohammadi-Aylar *et al*. (2010) used a pendulum impact apparatus for impact tests of two varieties of tomatoes. They found that no differences between two varieties based on rupture injury, whereas, impact energy and especially stage of ripeness had significant effect on all types of mechanical damage in tomato fruit. Also, the results showed that the severity and rate of latent damage increase progressively, through 24 to 72 hours of storage of fruits in natural conditions. Ripening stage is the major factor affect severity of latent damage through 72 hours after impact. The aim of the research was study some mechanical damage effecting properties on tomatoes during storage

MATERIALS AND METHODS

The tomato *Lycopersicon lycopersicum* samples of Castlerock variety were obtained from the local market in Assuit - winter season.

The Physical properties; the principal dimensions in terms of length (L), width (W) and thickness (T). as shown in (Fig. 1) were measured by digital caliper (accuracy of ± 0.01mm) made in China, and the following physical properties [arithmetic mean diameter (D_a), geometric mean diameter (D_g), aspect ratio (R_a), sphericity (ϕ) and surface area (S_a)] were calculated by the following equations (Mohsenin, 1986).

$$D_a = (L+W+T)/3 \qquad (1)$$

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

$$R_a = (W/L)*100 \qquad (3)$$

$$\phi = D_g/L \qquad (4)$$

$$S_a = \pi\, (D_g)^2 \qquad (5)$$

To obtained the mass a TAYO electrical balance made in Korea, (THB-600, max 600g) having accuracy of (±0.01 g) was used to weighed each tomato sample and the volume was determined by volume of displacement water.

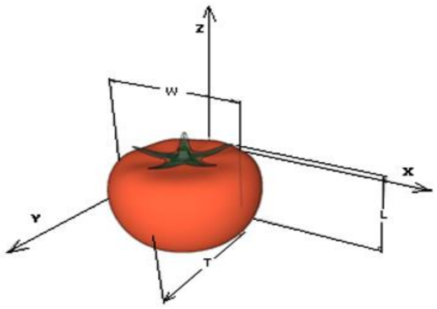


Figure 1. Three principal dimensions of tomato fruit (L, W, and T) and force direction X axis and Z axis.

Humidity and temperature measured and recorded each hour for all experiment time by using Arduino circuit shown in (Fig. 2). The circuit consisted of only 3 components Arduino uno board, 2 humidity and temperature sensors dht11 and SD_card module. Code developed to drive the circuit by using Arduino open-source software version 1.8.10 details shown in figure (3).

To obtain the changes in chemical properties of tomato during the experiment period total soluble solids (TSS), and pH were measured. The TSS was determined by digital refractometer model (Hanna Instruments HI 96801), 0-85% Brix Range and a resolution of 0.1% °Brix. The pH value of tomato juice was measured with a pH meter (Model STARTER3000) 0.to14 pH range with resolution 0.01 pH.

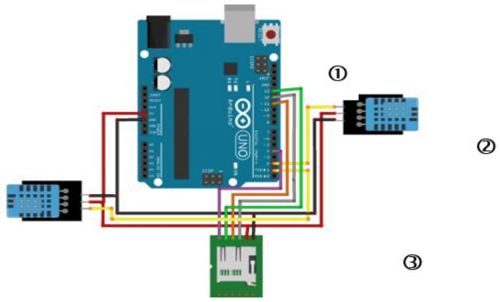
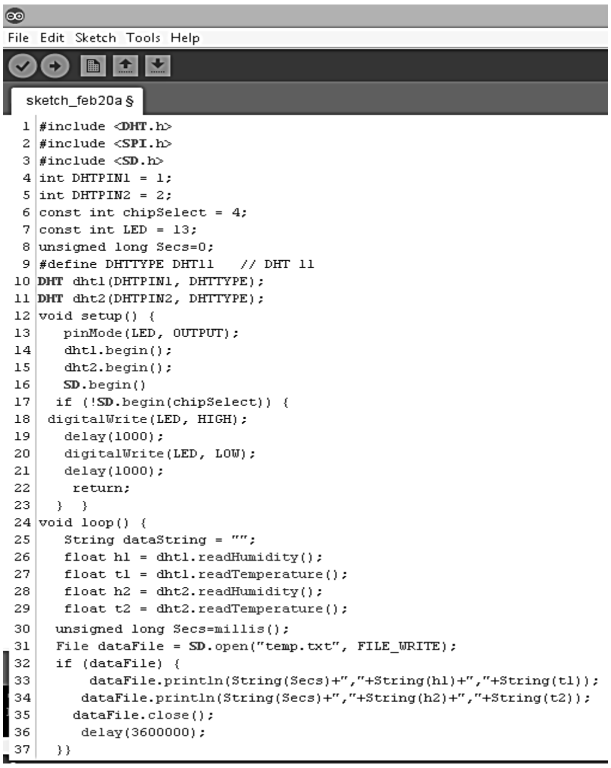


Figure 2. Developed Arduino microcontroller circuit components,

1-Arduino uno board 2-Dht11 humidity and temperature sensor 3-SD-card module




```
#include <DHT.h>
#include <SPI.h>
#include <SD.h>
int DHTPIN1 = 1;
int DHTPIN2 = 2;
const int chipSelect = 4;
const int LED = 13;
unsigned long Secs=0;
#define DHTTYPE DHT11   // DHT 11
DHT dht1(DHTPIN1, DHTTYPE);
DHT dht2(DHTPIN2, DHTTYPE);
void setup() {
   pinMode(LED, OUTPUT);
   dht1.begin();
   dht2.begin();
   SD.begin()
  if (!SD.begin(chipSelect)) {
 digitalWrite(LED, HIGH);
   delay(1000);
   digitalWrite(LED, LOW);
   delay(1000);
    return;
  }  }
void loop() {
   String dataString = "";
   float h1 = dht1.readHumidity();
   float t1 = dht1.readTemperature();
   float h2 = dht2.readHumidity();
   float t2 = dht2.readTemperature();
  unsigned long Secs=millis();
  File dataFile = SD.open("temp.txt", FILE_WRITE);
  if (dataFile) {
      dataFile.println(String(Secs)+","+String(h1)+","+String(t1));
     dataFile.println(String(Secs)+","+String(h2)+","+String(t2));
    dataFile.close();
     delay(3600000);
  }}
```

Figure 3. Developed Arduino sketch to read and record humidity and temperature.

Mechanical properties

The following mechanical properties were measured; coefficient of friction, and firmness. The friction angle was measured by an instrument fabricated in the workshop of Agricultural Engineering Faculty Al-Azhar University, Assuit branch. various materials wood, plastic, rubber, cartoon, and galvanized iron steel sheets were installed on the changeable plane to study the effect of these materials on the friction angle. the fruits are placed as a group bonded together on a horizontal surface then the angle of inclination is gradually increased until the fruits begin sliding without rolling. For each fruits group of an average sample of (5), the friction angles were determined.

Coefficient of friction (μ) of tomatoes was calculated by measuring the angle at which tomatoes started moving on four surfaces of plastic, cartoon, wood and rubber sheets.

$$\mu = \tan(\alpha)$$

The firmness of tomatoes was measured using a penetrometer device type (ft 327) developed in Italy with an accuracy of 0.1 kg. Firmness was measured at three places on the equatorial area using three fruits per treatment. The readings were expressed in (kg) then converted to N/cm^2 by dividing the penetration force (reading per kg * 9.81) by the area (0.28 cm^2) of the cylindrical probe, which had 0.6 cm diameter.

The number of fruits required for this experiment = 2 treatments *2 positions*2 storage conditions* 4 storing periods * 3 reps. = 96 fruits. plus 27 tomato fruits used as control in and out of refrigerator

Treatments include using 2 probes namely pressure probe (flat) and penetration probe (30˚ cone probe) as shown in (Fig. 4) in two positions (side and top of tomato fruits) with two storage methods (cooling at refrigerator and room temperature). Four storage periods include (5,10,15and 20) days.

Device shown in Figs (4 and 5) Geasa (2021) was used to simulate mechanical damage. The device programmed to compress each sample for 10 mm with constant linear speed of probe 0.31 mm/s. Force affected on tomato sample was measured simultaneously by a load cell and recorded on laptop. To determine the effect of treatments on deterioration of tomato, after experiments were done, data was collected every five days. The collected data includes weight, pH, total soluble solids (TSS), and penetration force, (penetration force was taken from three places on the fruit; top, bottom and side of the sample then the average was calculated)

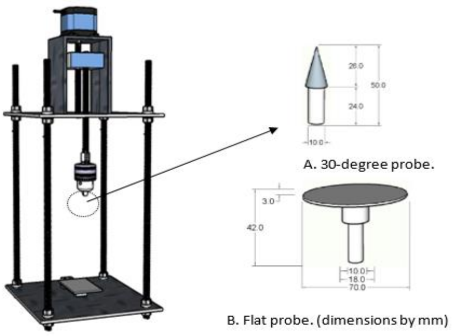


Figure 4. Developed test device and their probs.

Figure 5. Test device on act

RESULTS AND DISCUSSION

1. Physical and mechanical properties

The physical properties of tomato are reported in Table 1. The mean length (L), width (W), thickness (T), arithmetic mean diameter (D_a), geometric mean diameter (D_g), surface area (S_a), sphericity (ϕ), aspect ratio (R_a), mass (M), volume (V), and true density of the tomato(ρ) were 48.78, 56.48, 53.27, 52.84, 52.71mm, 8759.62 mm^2 , 1.08 %, 1.16, 83.67 g, 87.85 cm^3 , and 0.96 g/c m^3 , respectively. The most essential characteristics utilized to reduce waste during packaging and shipping are the weight, size, and form of agricultural products. Sphericity and actual density are particularly important in the design of transmission systems, grading, and cleaning the product.

Table 1. The physical properties of tomato fruits.

	Max.	Min.	Mean	S.D.	C.V.
L (mm)	57.20	40.95	48.78	3.79	7.77
W (mm)	64.00	47.75	56.48	4.28	7.58
T (mm)	60.10	46.10	53.27	3.82	7.17
Da (mm)	58.48	46.30	52.84	3.44	6.52
Dg (mm)	58.28	46.28	52.71	3.42	6.50
Ra	1.35	0.97	1.16	0.09	8.02
Sa (mm^2)	10666.27	6725.10	8759.62	1127.00	12.87
Φ	1.21	0.97	1.08	0.05	4.99
V (cm^3)	129.00	58.00	87.85	17.28	19.66
M (gm)	112.40	55.86	83.67	15.26	18.24
ρ (g/cm^3)	1.02	0.81	0.96	0.05	5.58

The static friction coefficients:

Table 2 shows the findings of static friction coefficients calculated for five surfaces manufactured from wood, plastic, rubber, cartoon, and galvanized iron steel (G.S.) sheets. The average static friction coefficients were 0.4, 0.27, 0.33, 0.26, and 0.29, respectively at the above surfaces . Tomatoes have the least friction on the surface of cartoon sheets, according to their static friction coefficients (0.26). This rate is substantially lower than the rates achieved in the other treatments, and the transfer of tomatoes necessitates a lower gradient angle. Also, the wood surface has the highest static friction coefficient (0.4)

Table 2. The static friction coefficients of tomato fruits.

Surface type	Mean	Min	Max	SD	CV, %
Wood	0.398	0.344	0.445	0.034	8.610
Plastic	0.268	0.231	0.306	0.025	9.329
Rubber	0.331	0.306	0.364	0.021	6.224
Cartoon	0.257	0.213	0.287	0.028	10.878
G. S.	0.289	0.213	0.325	0.036	12.443

Storage temperature C^o and relative humidity %.

From Table (3), the values of temperature ranged from 15.4 to 6.2 C^o with a mean value of 9.9 ± 5 C^o and ranged from 24.2 to 8.1 C^o with a mean value of 15.8 ± 7 C^o for refrigerator and room storage respectively. The values of relative humidity% ranged from 86 to 21 C^o with a mean value of 47.6 and ranged from 88 to 25 % with a mean value of 53.4 % for refrigerator and room storage respectively.

Table 3. Temperature C^o and relative humidity% throw the storage period.

Storage place		Max	Min	Mean	SD	CV%
Refrigerator	Humidity %	86	21	47.56	21.28	0.447
	Temp. C^o	15.4	6.2	9.9	2.22	0.224
Room	Humidity %	88	25	53.4	0.15	0.283
	Temp. C^o	24.2	8.1	15.8	4.4	0.278

Force and deformation affecting on tomato samples:

Simulation of mechanical damage on tomato fruit experimental shows several trends. As shown in figure (6) The tomato fruit's position has the greatest influence on its resistance to deformation. Tomato Z axis direction has the maximum resistance for deformation in all experimental treatments either pressure or penetration on the other hand X axis direction has minimum deformation resistance. Figure shows that there was a positive relationship between the force and deformation for all treatment. The findings of comparing the position of the tomato with the resistance to deformation demonstrate that 10 mm tomato deformation needs about 60 N by using flat probe and tomato at Z axis whilst the same deformation needs about 42 N only with tomato at X axis., as a result of that, tomatoes are preferably stacked in containers vertically. The same trend clearly appears with using 30˚ cone probe treatment with note that 10 mm deformation only needs about 13 and 5 N for vertical and side positions treatments respectively. so as much as possible, its necessary to keep the tomatoes away from sharp items. The figure also shows that after one minuets of treatment the pressure or penetration force decrease

The total soluble solid (TSS) related to storage periods.

Results during storage period are presented in Fig (7). The results show that the TSS increased by increasing storage time. For all the tomato samples, greater values were recorded at end of the storage period. That there was positive relationship between storage period and TSS. Salunkhe *et al.* (1974) explained that by soluble solids content increases with fruit maturity through biosynthesis process or degradation of polysaccharides.

The average TSS values for all samples stored in the cooled condition were lower than those stored in the room condition, which could be attributed to higher rates of degradation in the room ambience, also at same conditions the penetration force with 30 degrees probe was more influential in the TSS values of tomato samples compared to the flat pressure probe. The untreated samples had low TSS readings at same conditions (refrigerator and atmospheric room) increased from 8.1 % to 20.95 % and 21.5 % for increasing storage period from 0 to 20 days. Also, the average values of TSS for mechanical damage methods (penetration and pressure) increased from 8.1 % to 21.05 % and 21.4 % for increasing storage period from 0 to 20 days. For ending the storage time, the height value of TSS of 22.3 % was obtained at atmospheric storage method and mechanical penetration damage. But the lowest value of TSS of 19.8 % was obtained at storage refrigeration method and mechanical pressure damage. Increase in TSS of tomato fruits could be due to excessive moisture loss which increases concentration as well as the hydrolysis of carbohydrates to soluble sugars (Tigist *et al.* 2013)

pH values during experimental period:

Fig(8) displays the pH values of tomato treatments stored under ambient and cooling conditions The rate of increase in pH was correlate to the effect of mechanical damage; storage conditions and storage period The results showed acidity decreased by increasing of storage period in all treatments; also the rate of pH increased in the room condition was greater than the increase in pH values in the cooling condition. In general, side force treatments of the tomato samples had a greater impact on the pH value. This result seemed to confirm the literature information available on the pH values of tomato fruit; for example, Tigist *et al.* (2013) reported that tomato products are generally classified as acidic foods (pH<4.6). They also added pH below 4.5 is a desirable trait, because it halts proliferation of microorganisms. After storage period 20 days It has been observed that highest pH 4.93 recorded for mechanical damage by 30-degree probe, side position and at room ambience storage. On the other hand, the minimum pH reading 4.56 was recorded for control samples storage in the refrigerator. In general samples stored in cooling conditions had minimum values of pH, also the average values of pH for penetration mechanical damage by 30-degree probe were higher than the flat probe.

Firmness readings during experimental period:

Firmness is regarded as one of the most important indicators of tomato quality. The firmness of the fruit determines its marketing worth. As in all previous investigations, the firmness of all tomato samples decreased with increasing storage duration, as seen in Fig. (9) The activity of some endogenous enzymes involved in cell wall breakdown is primarily responsible for the decrease in firmness Shehata *et al.* (2021). After storage period 20 days, it has been observed that less firmness 1.5N/cm^2 recorded for mechanical damage by 30-degree probe, side position and at room ambience storage. On the other hand, the maximum firmness reading 2.8 N/cm^2 was recorded for samples without treatments and refrigerator storage. In general samples stored in cooling conditions had max values of firmness, also the average values of firmness for penetration mechanical damage by 30-degree probe were higher than the flat probe, and rapture of tomato skin may be accelerating the rate of deterioration.

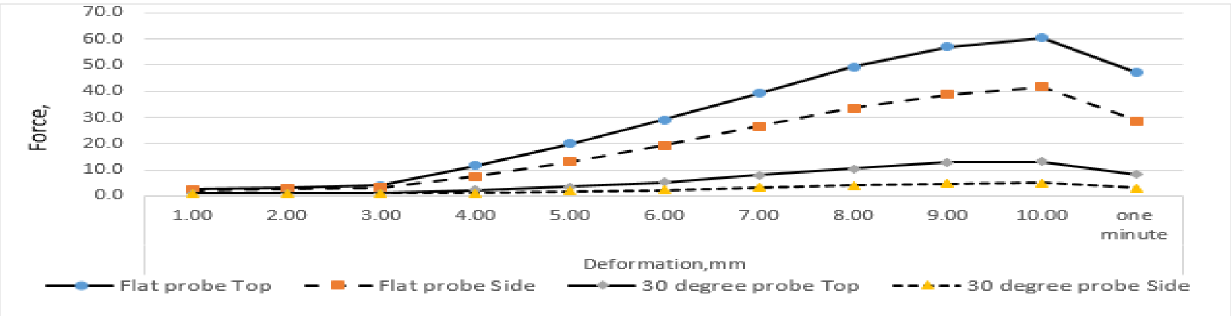


Figure 6. Effect of probe type and direction of force on force/deformation curve for tomato samples.

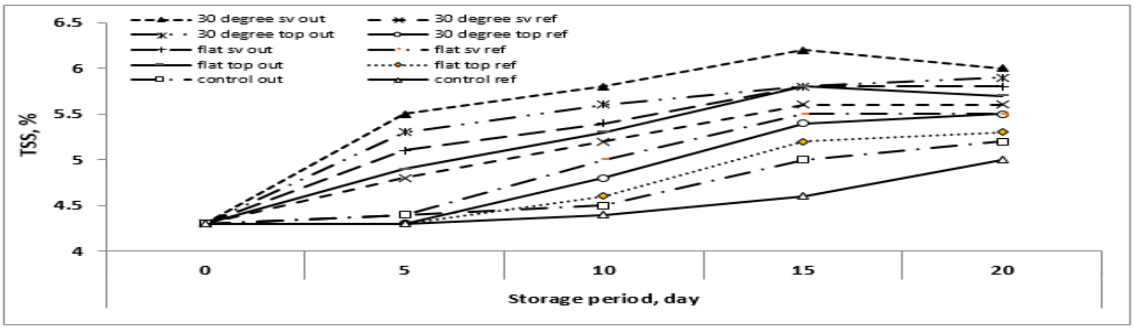


Figure 7. Effect of storage periods and experimental procedures on tomato T.S.S.

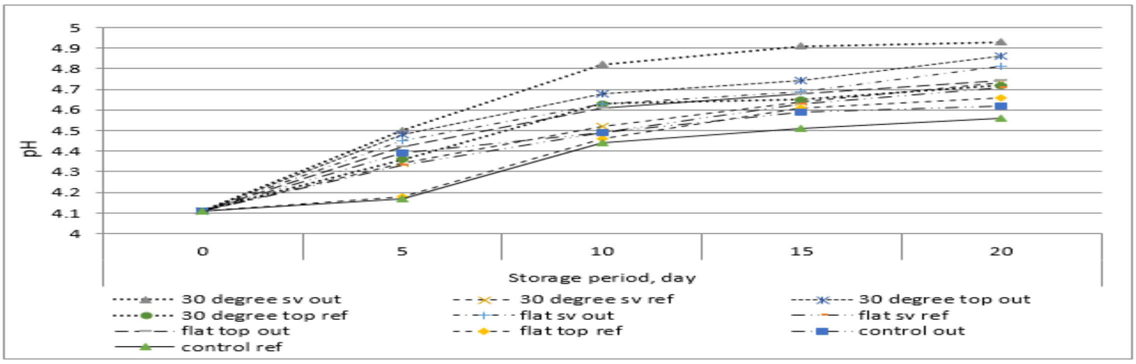


Figure 8. Effect of storage periods and experimental procedures on tomato pH.

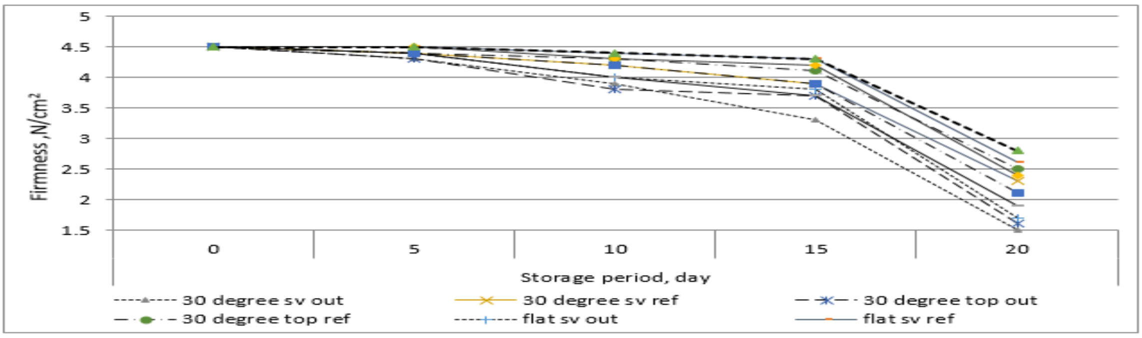


Figure 9. Effect of storage periods and experimental procedures on tomato firmness.

Tomato samples mass loss during experimental period:

The most important aspect in horticulture crop quality and shelf life is mass loss. As shown in Fig.(10), mass loss was affected by storage period, treatments, and interactions. Mass loss increased during the storage period for all treatments, as expected.

Water losses can be one of the main causes of deterioration, since it is not only resulting in indirect quantities losses but losses in appearance due to shriveling (Hassan *et al*.,2017). In general samples stored in refrigerator had minimum weight losses at all conditions. Also, the average values of weight losses for mechanical penetration damage by 30-degree probe were more than by pressure flat probe at same condition this may be due to rapture skin of tomato tends to more evaporation of water from samples

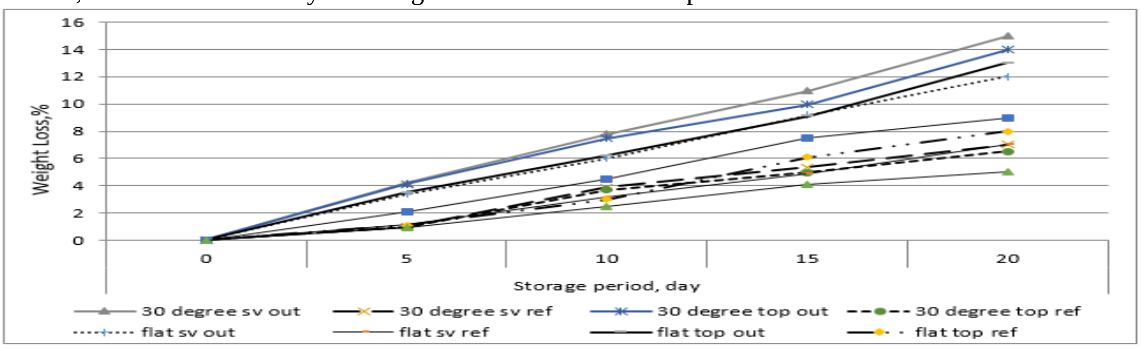


Figure 10. Effect of storage periods and experimental procedures on tomato mass loss.

CONCLUSION

The combination of high relative air humidity and a low refrigerator temperature reduces tomato water loss, potentially extending the fresh product's shelf life. The same patterns were seen by Shehata *et al*.(2021). Water loss from fresh products also causes adverse metabolic changes in plant cells, which activate enzymes, according to the researchers. These enzymatic activity hasten the ageing process and lower nutritional qualities. The effect of mechanical damage on mass losses and weight loss at increased compressibility could be explained by the fact that mechanical injury water vapor to pass through the damaged area. (Abu-Goukh and Elshiekh, 2008)

This research study the effect of mechanical damage in shelf time of tomato fruit. The results of study was found that the mechanical damage caused many effects on firmness, mass loss, total soluble solids (TSS), and pH. The study results show that effect of penetration damage on tomato fruit causing speed deterioration with compression damage. Results also show the relation of the compressibility and loading position, stack the tomatoes on the Z axis can increase its deformation resistance also the effect of cooling was very important in increase of shelf time the results of this experiment can be useful in a variety of scenarios, including long- and medium-term storage, quality control, transportation and marketing, growers, and consumers. Furthermore, additional research is recommended to investigate the effects of more types of mechanical damage on different tomato varieties.

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تأثير الضرر الميكانيكي على ثمار الطماطم تحت ظروف التخزين

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تسبب عمليات ما بعد حصاد الطماطم مثل التعبئة والتداول والنقل والتخزين مشكلة كبيرة للطماطم تؤدي الي التلف والتدهور. واهتم هذا البحث بدراسة بعض الأضرار الميكانيكية التي تؤثر على خصائص جودة الطماطم أثناء فترة التخزين. وذلك بمحاكاة الضرر الميكانيكي باستخدام جهاز تم تطويره مسبقا يستخدم لضغط عينة الطماطم لتحقيق مسافة تشوه أو إختراق تبلغ 10 مم. حيث إستخدام شكلان للأسلحة المستخدمة (الشكل المسطح والشكل المخروطي بزاوية رأس 30 درجة) علي محوري الثمرة X و Z وإستخدمت طريقتان لحفظ الثمار بعد المعاملة الحفظ داخل الثلاجة وفي أجواء الغرفة خلال فترات تخزين (5 و10 و15 و20 يوما). وتم قياس بعض الخصائص الطبيعية والميكانيكية وكذلك الكيميائية للثمار. وأفادت النتائج بأن أعلي مقاومة تشوة لثمرة الطماطم كانت 60 نيوتن مع إستخدام السلاح المسطح علي أعلي الثمرة مما يعني أن رص ثمار الطماطم بوضع رأسي يجعلها أكثر تحملا للإنضغاط بنسبة حوالي 30%. كما بينت التجربة تأثير الحفظ بالتبريد علي إطالة فترة الحفظ لثمار الطماطم لجميع المعاملات التجريبية أعلي قيمة لإختبار مقاومةالاختراق قدرها 2.8 نيوتن / سم 2 كانت للعينة بدون معاملة محفوظة داخل الثلاجة بينما أعلي قيمة لرقم الأس الهيدروجيني كانت في التخزين بجو الغرفة وإستخدام السلاح المخروطي وكانت 4.93 وفي نفس المعاملة تم تسجيل أعلي فقد في الوزن وهو 15.81٪ كذلك النتائج في مجملها تشير الي التأثير البالغ للضرر الميكانيكي علي ثمار الطماطم وضرورة حفظها من التعرض للأجزاء الحادة أثناء التداول فهي تؤدي إلي تدهور سريع في خصائص الثمار.