Physico-chemical Changes in Tomato (*Solanum lycopersicum* L.) Fruits as Influenced by Cultivation Systems and Modified Atmosphere Packaging

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ABSTRACT

Tomatoes are highly perishable and postharvest losses vary greatly among production areas and seasons of production. This study was conducted to evaluate the effects of open or protected cultivation system and postharvest modified atmosphere packaging (MAP) on the physical and chemical changes of tomatoes during ambient storage with temperatures ranging from 20 ^{0}C to 35 ^{0}C and relative humidity (RH) of 80% to 90%.

The cultivation system had no significant effect on the physico-chemical constituents. In contrast, MAP storage significantly influenced some of the storage parameters evaluated. Use of paper bags and 0.02mm-thick low density polyethylene bags with diffusion holes slightly delayed ripening, effectively reduced weight loss, minimized decay incidence and maintained better visual quality throughout the 12-day storage period relative to fruits stored in the open.

Key words: Tomato (*Solanum lycopersicum* L.), Modified Atmosphere Packaging (MAP), Cultivation systems, Physical parameters, Chemical parameters

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular cultivated vegetables worldwide. This crop belongs to the family solanaceae or nightshade family and is locally known as "kamatis". It is one of the most profitable crops in the Philippines with variety of uses and nutritional value. It is grown in small gardens for home consumption or in large farms for commercial purposes. It is one of the satisfactory income producing solanaceous crops. Its fruits are used for salads, pickles, sauces, catsup, preserves and soups. Some use it as a dip or (*sawsawan*), served as stewed, fried, raw, and baked (Vitug, 1989).

Tomatoes are sensitive to many production and environment-genetic interaction disorders. The continuous production of tomato is limited by the occurrence of warm temperatures, but a much more important factor that prevents growers in Eastern Visayas from producing tomatoes all year round is the adverse effect of rain particularly during the months of October to December (Apilar, 2002). Hence, the use of rain shelter or structure with plastic sheet roofing to protect plants from heavy rain is seen as a potential farming technique that would allow better production of tomatoes; this technique is known as "protected cultivation". Results of several researches on protected cultivation of crops conducted from other countries as well as in the Philippines are promising.

Aside from yield increase, tomatoes grown in protective structure were reported to have better physico-chemical characteristics, retain firmness longer, have longer shelf life (Apilar, 2002), are sweeter and more tender (Garnaud, 1988), and have higher sugar content and lower acidity than those grown in open field conditions (Kim, 1990). Since the environment inside the protected structure is different from that in the open, harvest from crops in a different environment may have different postharvest behavior.

Studying postharvest behavior of tomatoes is one way to determine the reduction of postharvest losses in order to increase food availability to the growing world population. The changes that occur after harvest are vitally important to consider and is essential for the attainment of the desired degree of eating quality. Some strategies for loss prevention include: use of genotypes that have longer postharvest life, use of integrated crop management systems and good agricultural practices that result in good keeping quality of the commodity, and use of proper postharvest handling practices in order to maintain the quality and safety of fresh produce

(Kader and Rolle, 2004).

The accumulation of carbon dioxide and depletion of oxygen to beneficial levels by the application of Modified Atmosphere Packaging (MAP) is known to extend the postharvest life and quality of many horticultural commodities (Zagory and Kader, 1988; Kader *et al.*, 1989**).** Indeed MAP has been used as a supplement or even a substitute for refrigeration to prolong storage life of fresh products during transportation and retail handling (Kader *et al.*, 1989; Shirazi and Cameron, 1992). Kader *et al.* (1978) reported that Controlled Atmosphere (CA) storage could retard quality deterioration in fresh tomato in a manner similar to low temperature. Several other researchers have reported similar results. However, the high degree of atmospheric regulation associated with CA is capital intensive and expensive to operate especially in developing countries, and is, therefore, amenable for long-term storage of commodity like apple (Zagory and Kader, 1988; Cheng and Shewfelt, 1988**).** Alternatively, an inexpensive way of delaying fruit ripening is the use of MAP, where fruits are sealed in semipermeable plastic packages that enable the development of a beneficial gas atmosphere created and maintained by the interaction of fruit respiration and gas diffusion through the packaging film. Most of the work done on postharvest handling of tomato has been done in the developed countries where emphasis has been laid on low temperature effects probably due to availability of cooling facilities on the fruit quality. Moreover, tomato fruit being sensitive to chilling temperature can only be stored safely at above 12°C to prevent from chilling injury and maintain color and flavor profile (Artes and Escriche, 1994). Although optimum quality of tomato is attained through vine ripening, ripe tomato fruits are perishable and very labile to transport damage that consequently leads to quality deterioration and wastage (Nakhasi *et al.*, 1991). This is especially so common in developing countries due to poor postharvest handling systems and transportation of fruits and vegetables over rough roads and uneven surfaces (Mathooko, 1995). For this reason fruits intended for distant markets are usually harvested at mature-green or breaker stages so that the fruits can endure the rigors of handling, thus, maximizing shelf life (Gong and Corey, 1994). Most recently, polyethylene packaging of fruits including tomatoes during retail marketing has become popular all over the world.

Recognizing the increasing demand for fresh vegetable of better quality, manipulation of the different factors that affect postharvest behavior of tomato is one of the alternative solutions. This study aimed to

investigate the effect of cultivation systems and MAP on the physical and chemical changes of tomato during storage at ambient conditions.

MATERIALS AND METHODS

Preparation of Fruit Samples

Freshly harvested mature green tomato *var. Diamante Max* fruits produced in the open field and under protective structure were obtained from the ACIAR (Australian Center for International Agricultural Research) Vegetable Project. The fruits were selected for uniformity in size, color, and absence of blemishes and fungal infection. These were brought to the Postharvest Technology Laboratory, Department of Horticulture, VSU, Visca, Baybay City, Leyte. The fruits were washed with tap water and air-dried prior to the conduct of the experiment.

Experimental Design and Treatments

The experiment was conducted in 2 x 4 factorial in Completely Randomized Design (CRD) with 3 replications. Ten freshly harvested tomato fruit samples were used per treatment combination per replication.

The treatments were designated as follows:
Factor A. Systems of Cultivation
C_1 – Open field cultivation
C_2 – Protective cultivation

Factor B. Modified Atmosphere Packaging (MAP)
P_0 – Without packaging, control
P_1 – Low density polyethylene (LDPE) bags without diffusion holes
P_2 – LDPE bags with 8 diffusion holes
P_3 – Brown paper bags

The ten (10) tomato fruits per replicate were placed inside each type of packaging while the control fruits were placed on plastic trays. LDPE bags with 0.02 mm thickness usually used by retailers were sealed using thermal sealer while the brown paper bags with 0.01 mm thickness were sealed using stapler. Storage was done at ambient with temperatures ranging from

20 ^{0}C to 35 ^{0}C and relative humidity (RH) of 80% to 90%.

Measurement of Physical Changes

Color Changes. The changes in peel color were determined every after three (3) days of storage using the following color index (CI) scale (Acedo, 1999):

CI	Description
1	green, varying from light to dark
2	breaker, first trace of yellow, orange or red
3	more green than yellow, orange or combination of both
4	more yellow, orange or red than green
5	orange or red with a trace of green
6	full orange or red

The number of days to reach full ripe stage (CI 6) was taken as a measure of the ripening period. Data collections were terminated when the fruit reached CI 6.

Firmness Index (FI). This was assessed by finger feel every after three (3) days of storage using the following rating scale of Acedo (1999).

FI	Description
1	very firm
2	firm
3	moderately firm
4	soft
5	very soft

Weight Loss. The initial weight and the weight of the fruits every after three (3) days of storage were measured. Weight loss at each observation period was expressed as percentage of the initial weight.

Decay Incidence. The fruits that showed signs of decay or disease infection were counted every after three (3) days of storage and expressed as percentage of the total number of samples. Severity of the disease infection was assessed using the following disease severity index (DSI):

DSI	Description
1	No decay
2	Less than 20% of fruit area showed decay
3	21% to 40% of fruit area showed decay
4	41% to 75 % of fruit area showed decay
5	76% and above of the fruit area showed decay

Visual Quality Rating (VQR). The physical appearance of each tomato fruit was assessed every other three (3) days using the following visual quality rating (VQR) (Subere,1997):

VQR	Description
9	excellent, no defects
7	good, defects minor
5	fair, defects moderate
3	poor, defects serious, limit saleability
2	limit edibility
1	inedible under usual condition

Measurement of Chemical Changes

*Total Soluble Solids (TSS).*This was measured at CI 6 or prior to termination of the study. The TSS was determined using an aliquot of juice extracted using a juice extractor. An Atago N, hand refractometer with a range of 0 to 32 $^\circ$Brix and resolutions of 0.2 Brix was used to determine TSS by placing 1 to 2 drops of clear juice on the prism.

Titratable Acidity (TA). Tomato juice was extracted from the sample with a juice extractor and clear juice was used for the analysis of TA. The titratable acidity was obtained by titrimetric method using standardized 0.1 N sodium hydroxide (NaOH) solution and 0.1% phenolphthalein as indicator. Percent TA in % citric acid was computed using the formula:

$$TA \ (\%citric \ acid) = \frac{V \times N \times Me}{W} \times 100$$

Where:
V = volume of NaOH added until faint pink color developed, ml
N = normality of NaOH
Me = milliequivalent weight of the predominant citric acid tomato
     = 0.064
W = weight of the fruit samples, gram

pH. The pH of the fruit juice sample was measured using the Hanna electric pH meter.

Lycopene. Lycopene extraction was based on the method of Fish *et al*. (2002) with slight modifications. In brief, tomato fruits were finely ground for 1 min to puree using a Vita-Mix 3600 stainless steel blender (Vita-Mix, Inc., USA). Ground tissues were kept on ice and out of light after preparation and until assayed. An approximate 1 g of the puree (without seeds) were put in 50 mL PTFE aluminum wrapped test tubes while they were on ice. Lycopene extraction solution (39 ml) consisting of hexane, 0.05% (w/v) butylatedhydroxytoluene (BHT) in acetone and 95% ethanol in a ratio of 1:1:1 were added to the tubes and were shaken for 10 min at 180 rpm using table top shaker while they were on ice. To each tube, 6 ml of cold double distilled water was added and agitated for an additional of 5 min for better separation of polar and non-polar compounds. Tubes was then removed from shaking and left for 15 min in room temperature for separation into polar and non-polar layers. Supernatant was put into new 15 ml aluminum wrapped test tubes and kept at -80 °C for further experiments. The absorbance of supernatant (hexane layer) containing lycopene was read three times using Beckman DU-64 spectrophotometer at the wavelength of 503 nm VIS lamp. Absolute hexane was used as blank. The amount of lycopene in tissues was then estimated by the following formula:

$$\text{Lycopene (mg/kg)} = (x/y) \times A_{503} \times 3.12$$

Where:
x = the amount of hexanes (ml)
y = the weight of fruit tissue (g)
A_{503} = the absorbance at 503 nm
= the extinction coefficient

Dry matter content (DMC). This was determined by oven-drying the tomato fruit sample at 60°C until constant weight. DMC was calculated as percentage of fresh weight.

$$\% \, DM = \frac{DW}{FW} \times 100$$

Sugar content analysis. This was done using the anthrone method (Cagampang and Rodriguez, 1980). The sample was determined using a reagent of 80% ethanol , 50% peach lonia acid, 26% perchlorine acid, and

 0.2% anthrone in standard glucose solution dissolved in 10 mg glucose in 100 mL of 26% HCLO4 (Starch standard). For sugar, 10 mg glucose in 100 mL of 80% ethanol was dissolved.

The lycopene and total sugar analyses were done at Central Analytical Laboratory, PhilRootCrops, VSU, Visca, Baybay City, Leyte, while pH, total soluble solids, and titratable acidity were analyzed at the Postharvest Technology Laboratory of the Department of Horticulture, VSU, Visca, Baybay City, Leyte.

Statistical Analysis

Results were analyzed by performing analysis of variance (ANOVA). When ANOVA showed significant differences between treatments, comparison of treatment means was done by HSD (Honest Significant Difference) test. ANOVA and HSD were done using the Motorola Statistical Analysis Tool (MSTAT) program.

RESULTS AND DISCUSSION

Physical Characteristics

Peel color development. Shown in Table 1 are the number of days of storage and mean ratings of peel color developed in tomato fruits from harvest to full ripe (CI 6) stage (Fig. 1a-1d) as influenced by systems of cultivation and modified atmosphere packaging (MAP). The number of days to full ripe (CI 6) and mean ratings of peel color were not significantly affected by the systems of cultivation. However, fruits obtained under house-type protective structure took slightly longer period to reach CI 6 as compared to the fruits derived from plants grown in the open field.

This is similar with the findings of Kliewer and Lider (1968) who found that grapes on a bunch exposed to direct sunlight ripen faster than shaded berries. The fruits produced from the two methods of cultivation reached almost 12 days before the color changed to full orange or red.

Moreover, fruit peel reddening was significantly retarded by the type of storage. Fruits stored in paper bags and plastic bags especially in sealed low density polyethylene (LDPE) bags with diffusion holes had slower peel reddening. This could be due to the accumulation of CO_2 in the polyethylene bags which inhibited the ethylene action, thus, slowed down the ripening process (Bautista and Esguerra, 2007). Bautista and Acedo (1987) as cited

by Mante (1992) stated that it is possible that ethylene emitted by the fruits is the cause of ripening inside the completely sealed polyethylene bag without perforation. However, this is contradicting to the present study wherein tomato fruits stored in LDPE without perforations did not fully change in color and were totally decayed. This may be due to the composition of the gases within a package that resulted from the interaction of a number of factors such as the permeability characteristics of the package, the respiratory behavior of the plant material and the environment. Also, temperature and RH significantly affected film permeability and thereby the O_2 and CO_2 content of the package. On the other hand, the control stored under ambient condition showed an entirely different pattern as it displayed faster ripening rate due to low relative humidity during storage with an average of 89.4%. Unlike in MAP, a relatively higher relative humidity was maintained and has been found to slow down fruit ripening changes (Xue *et al.*, 1995 and 1996).

Table 1. Influence of cultivation system and MAP on peel color development of tomato var. 'Diamante Max' during 12 days of storage at ambient condition

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! ỳ*Systems of Cultivation*					
/ ∾Æ‖©¨§	⸗ỳ⸗	ỳ⸗	⸗ỳ⸗	ỳ⸗	ỳ⸗
(Ø⊔≥-type protective structure	⸗ỳ⸗	⸗ỳ⸗	⸗ỳ⸗ للّٰه	ỳ⸗	ỳ⸗
" ỳ*Modified Atmosphere Packaging* (MAP)					
7 ҨҘӨ⊔¥∾°£´°ß⑃B	ỳ⸗	ỳ⸗	ỳ⸗°	ỳ⸗°	⟨ỳ⸗a
0¨°¥Œ∾°£´°ß⑃B X $ 0%¢°ß≥Ø‖ ⸗ỳ□□ mm thickness without diffusion holes)	⸗ỳ⸗	ỳ⸗	ỳ⸗¢	ỳ⸗ ¢	ỳ⸗ ¢
0¨°¥Œ∾°£´°ß⑃B X $ 0%¢°ß≥Ø‖ ⸗ỳ□□ mm thickness with 8 diffusion holes)	⸗ỳ⸗	ỳ⸗	ỳ⸗°	ỳ⸗°	⟨ỳ□°
0°∾≤∾°£´°ß⑃B - Brown paper bags of 0.01 mm thickness)	ỳ⸗	ỳ⸗	ỳ⸗°	ỳ⸗°	⟨ỳ□°
#6 Ẍ Ψ	–	□ỳ⸗لّٰه	□□ỳ⸗	□□ỳ⸗	□□ỳ⸗لّٰه

Means in the same column having a common letter or without letter designation are not significantly different from each other at 5% level, HSD. Color Index: 1 – green, varying from light to dark; 2 – breaker, first trace of yellow, orange or red; 3 – more green than yellow, orange or combination of both; 4 – more yellow, orange or red than green; 5 – orange or red with a trace of green; 6 – full orange or red

Figure 1a. Tomato (*Solanum lycopersicum* L.) fruits var. 'Diamante Max' grown under A. open field and B. house-type protective structure after 12 days of storage at ambient condition (P_0 – Control).
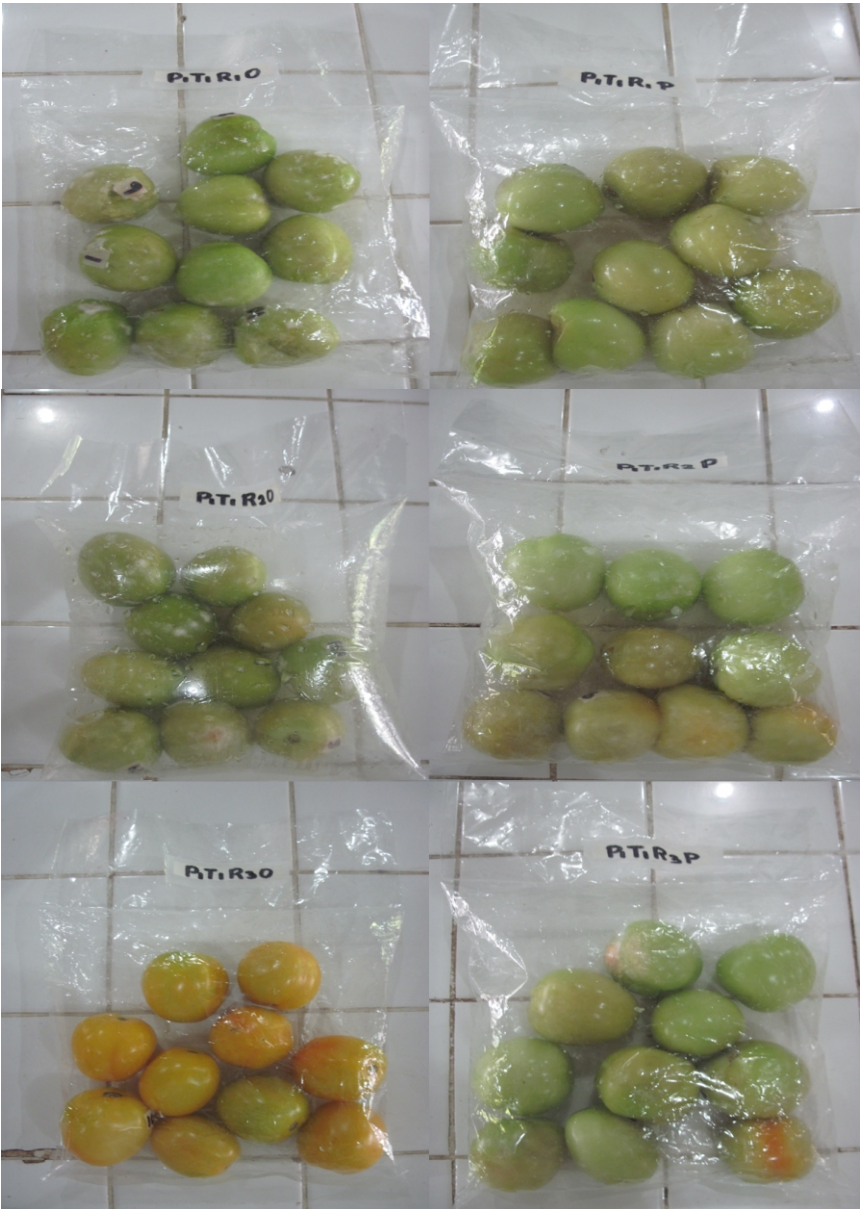
Figure 1b. Tomato (*Solanum lycopersicum* L.) fruits var. 'Diamante Max' grown under A. open field and B. house-type protective structure after 12 days of storage in LDPE without diffusion holes (P1).
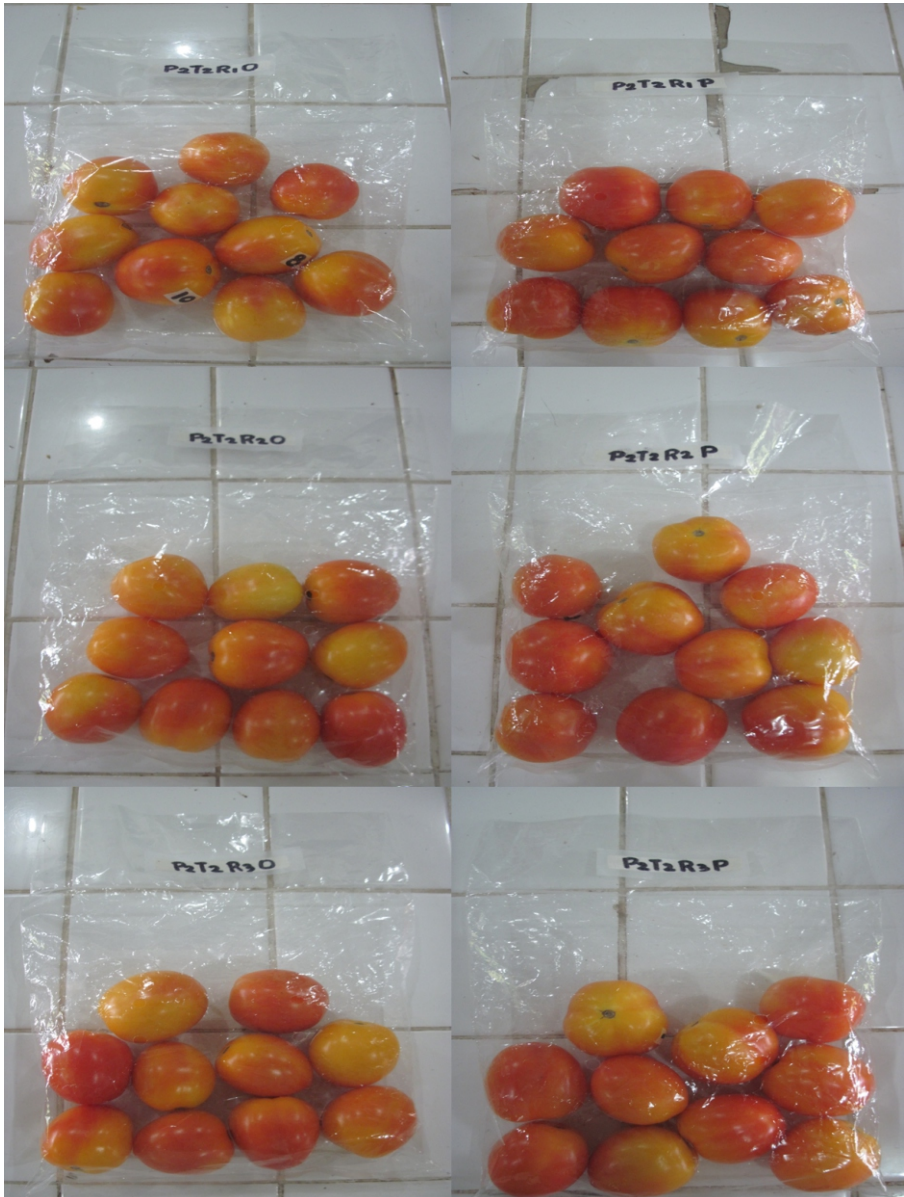
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Figure 1c. Tomato (*Solanum lycopersicum* L.) fruits var. 'Diamante Max' grown under A. open field and B. house-type protective structure after 12 days of storage in LDPE with 8 diffusion holes (P2).

Figure 1d. Tomato (*Solanum lycopersicum* L.) fruits var. 'Diamante Max' grown under A. open field and B. house-type protective structure after 12 days of storage in Brown paper bags (P3).

Additionally, the levels of O_2 and CO_2 within a package depend on the interaction between commodity respiration and the permeability properties of the packaging film and/or microperforations (Beaudry *et al.*, 1992; Kader *et al.*, 1989). One advantage of MAP with perforation or diffusion is that it results in a greater accumulation of CO_2 relative to reduction of O_2 compared to MAP with no perforations or diffusion (Beaudry *et al.*, 1992). Likewise, it serves as a primary route of gas exchange while the other one controls the movement of O_2 and CO_2 into or out of the package, respectively.

Fruit firmness. Fruits softened with storage and the rate of softening was significantly affected by the method of storage but was not significantly affected by the systems of cultivation (Table 2). Tomato fruits stored especially in sealed LDPE bags without diffusion holes showed higher rate of softening of 4.1 after 12 days of storage compared to the other treatments. This could be due to some limiting factor of the package, i.e., the appearance of molds associated with high RH. Several other researchers have noted condensation and/or mold and bacterial development in MAP systems (Grierson, 1969; Hardenburg, 1951; Scott *et al.*, 1964). This was also evident in the present study. First, the fungus and bacteria were grown on the fruit's exocarp, or outer skin. This process is directly affected by moisture, temperature, and RH. Because water accounts for a large percentage of a fruit's mesocarp (interior), water transpiration is a primary factor in the way a fruit decays and loses internal mass.

Additionally, the high disease severities of the rotten parts of tomatoes were soft and more prone to collapse. Loss of turgor also affects firmness of fruits (Beaulieu and Gorny, 2001). According to Harker *et al.*, (1997), the excess internal pressure of cells provides the hydrostatic component of cell and tissues strength and also influences the brittleness of the cell wall. Clearly, cell turgor has a major function in determining tissue strength, and changes in turgor are an integral part of fruit softening.

Moreover, softening is attributed to changes in the structure and composition of cell walls, including disassembly of the pectic matrix (Rose *et al.*, 1998), mediated at least in part, by the sequential action of pectinmethylesterase and endopolygalacturonase (Brummell and Harpster, 2001). Themman *et al.* (1982) reported that polygalacturonase (PG) and pectinesterase (PE) are the important enzymes involved in fruit softening by solubilizing the polygalacturonic acid in the pectin fraction of the cell walls during ripening. Grierson and Tucker (1983) further reported that PG activity increased while firmness decreased with progressive stage

of maturation and its synthesis only occurs in response to ethylene. In addition, Huber (1983) and Thakur and Pandey (1999) stated that polygalacturonase enzyme governs the firmness of tomato fruits.

Table 2. Influence of cultivation system and MAP on firmness quality of tomato var. 'Diamante Max' during 12 days of storage at ambient condition.

4◂•°¥• Æ≳	$°π≥∅¶ storage				
	▯	▯	▯	▯	▯▯
! ỳ*Systems of Cultivation*					
/ ∞Æ¶©˙§	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯
(∅µ≳-type protective structure	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯
" ỳ*Modified Atmosphere Packaging* (MAP)					
7 ⓒ⅍∅µ¥∞°£´°ß⒞⒝	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯	2.5 b
0¨≳⅍⒞ ∞°£´°ß⒞⒝ ₓ $ 0%¢°ß≥∅¶ ▯ỳ▯▯ mm thickness without diffusion holes)	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯a
0¨≳⅍⒞ ∞°£´°ß⒞⒝ ₓ $ 0%¢°ß≥∅¶ ▯ỳ▯▯ mm thickness with 8 diffusion holes)	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯b
0°∞◂≤∞°£´°ß⒞⒝ - Brown paper bags of 0.01 mm thickness)	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯	▯ỳ▯b
#6 ₓ Ψ	–	–	▯▯ỳ▯	▯▯ỳ▯	▯▯ỳ▯

Means in the same column having a common letter or without letter designation are not significantly different from each other at 5% level, HSD. Firmness Index: 1 – very firm; 2 – firm; 3 – moderately firm; 4 – soft; 5 – very soft.

Generally, a characteristic of the ripening process common to most fruits is a decrease in fruit firmness. According to Pilnik and Voragen (1970) and *Ali et al.* (2004), loss in firmness is shown to be associated with the activity of cell wall degrading enzymes and this activity could lead to structural alterations in cell walls. Harker *et al.* (1997) reported that many fruits soften during ripening, a process primarily associated with microstructural changes in the cell walls of the parenchyma cells. The parenchyma cells have non-lignified walls and are separated from the neighboring cells by a morphologically distinct region known as the middle lamella which is rich in pectins.

<u>Weight loss</u>. It is evident from Table 3 that the percentage weight loss increased significantly as the ripening proceeded. This was due to the uncontrolled ripening especially in control fruits which showed a sudden increase in ethylene production and respiration rate. This higher respiration rate also resulted in higher transpiration of water from the fruit surface which led to increase in percentage of weight loss (Sergent and

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Moretti, 2004). On the other hand, the systems of cultivation did not significantly influence the weight loss. Conversely, MAP significantly minimized weight loss while comparable weight loss was observed between the control and those packed with paper bags. It was also observed that weight loss of tomato fruits packed in LDPE with and without diffusion holes were not significantly different from each other. The present result was in agreement with Sammi and Masud (2007) where they found that packaging significantly reduced the weight loss from the fruits through every stage of ripening. Likewise, Babitha (2006) found that weight loss was significantly lower in MAP both under ambient and cold storage. According to Onwuzulu *et al.* (1995) and Geeson *et al.* (1985) that this could be attributed to the maintenance of high humidity in the micro-atmosphere within the packages by the respiring fruits and due to low water vapor transmission rates of packaging material.

Table 3. Influence of cultivation system and MAP on the cumulative loss in weight (%) of tomato fruits var. 'Diamante Max' during storage at ambient condition

Treatments	Days of storage		
	6	9	12
A. *Systems of Cultivation*			
Open Field	1.1	1.8	2.8
House-type protective structure	1.0	1.6	2.4
B. *Modified Atmosphere Packaging* (MAP)			
Without packaging	1.9 a	3.0 a	4.1 a
Plastic packaging (LDPE bags of 0.02 mm thickness without diffusion holes)	0.4 b	0.6 b	1.5 b
Plastic packaging (LDPE bags of 0.02 mm thickness with 8 diffusion holes)	0.4 b	0.9 b	1.4 b
Paper packaging - Brown paper bags of 0.01 mm thickness)	1.4 a	2.4 a	3.3 a
CV (%)	37.9	26.3	27.1

Means in the same column having a common letter or without letter designation are not significantly different from each other at 5% level, HSD

The reduced weight loss of fruits held under MAP especially those sealed in LDPE bags without diffusion holes is most likely due to the high RH maintained inside the polyethylene bags. The relatively high disease severity enhanced faster rates of transpiration and thus, water loss. Likewise, the completely sealed LDPE bags appeared to have trapped the water vapor transpired from the fruit as shown by the water droplets inside the bag which is a consequence of condensation. As a result, a humid

condition was maintained inside the polybag which resulted to low moisture loss of the stored fruits. It has been established by Smith (1977) as cited by Subere (1997) that decreasing the moisture deficit slows down the rate of moisture transfer from the commodity to the external atmosphere which is a major factor to weight loss in perishable commodity. In addition, the condition of high CO_2 and low O_2 inside the sealed polybag may have also reduced the rate of respiration and hence, the rate of dry matter loss.

Decay incidence. The degree and incidence of decay in tomato fruits were not significantly affected by the system of cultivation but were significantly influenced by the method of storage (Table 4). The fruits packed with LDPE without diffusion holes had significantly higher incidence of decay than the other treatments. The incidence of decay ranged from 0 to 20%, suggesting that tomato fruits can be stored longer without too much decay. This can be shown in the severity of decay, which was less than 2.0 or 20% of the fruit area was infected by microorganisms.

Table 4. Influence of cultivation system and MAP on incidence and severity of decay in tomato var. 'Diamante Max' at 9 and 12 days of storage at ambient condition

4⊲°¥•Æ≥	Days of storage		12	
	$•£°π			
	(%)	Degree*	(%)	Degree*
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/ ∞•Æ&©¨§	ẏ	ẏ	23.3	2.0
(Øμ≥-type protective structure	ẏ	ẏ	21.7	2.0
"ẏ- Ø§¶§ !¥Ø∞®≤ 0°£´°ß©Æ X ! 0Ψ				
7 ©ℝØμ¥∞£´°ß©Æ	0.0 b	1.0 b	0.0 b	1.0 b
0¨°≥¥© ∞£´°ß©Æ X $ 0%¢°ß≥Ø¶ 0.02 mm thickness without diffusion holes)	20.0 a	3.7 a	90.0 a	5.0 a
0¨°≥¥© ∞£´°ß©Æ X $ 0%¢°ß≥ of 0.02 mm thickness with 8 diffusion holes)	0.0 b	1.0 b	0.0 b	1.0 b
0°∞≤∞£´°ß©Æ - Brown paper bags of 0.01 mm thickness)	0.0 b	1.0 b	0.0 b	1.0 b
#6 X Ψ	ẏ	17.3	25.7	-

Means in the same column having a common letter or without letter designation are not significantly different from each other at 5% level, HSD. Disease Severity Index: 1 – no decay; 2 – less than 20% of fruit area showed decay; 3 – 21% to 40% of fruit area showed decay; 4 – 41% to 75% of fruit area showed decay; 5 – 76% and above of the fruit area showed decay.

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Alsadon *et al* (2004) reported that at least one or more of the fungus groups such as *Alternaria* spp., *Fusarium*spp., *Rhizopus* spp., and *Stemphyllus* spp. are known to infect tomato fruits during storage. Similar findings of Sommer *et al.* (2002 as cited by Alsadon *et al.*, 2004) indicated that the first three fungus groups generally infect tomato fruits during storage.

 Visual quality and shelf life. The visual quality of the fruits decreased with storage and this decrease was more rapid under MAP using plastic packaging without diffusion holes (Table 5). MAP-stored fruits especially sealed in LDPE bags without perforations reached the limit of marketability stage (VQR 3) after 12 days of storage compared with other treatments under different systems of cultivation. The primary cause of quality deterioration of MAP-stored fruits was due to softening and decay which partly contributed in reducing shelf life of the fruits. The decay was favored particularly at the later part of the storage period (Table 4) as has been observed also in earlier studies (Reyes, 1990; Ambi, 1992; Mante, 1992; Cañete, 1993; and Doria, 1994). The decrease of VQR in tomato fruits stored in plastic packaging without diffusion holes was attributed mostly by disease as shown by its high disease severity rating after 9 and 12 days of storage (Table 4).

Table 5. Influence of cultivation system and MAP on visual quality of tomato var. 'Diamante Max' at 12 days of storage

Treatments	Days of storage				
	0	3	6	9	12
A. *Systems of Cultivation*					
Open field	9.0	9.0	9.0	8.9	8.0
House-type protective structure	9.0	9.0	9.0	8.9	7.7
B. *Modified Atmosphere Packaging* (MAP)					
Without packaging	9.0	9.0	9.0	9.0	9.0 a
Plastic packaging (LDPE bags of 0.02 mm thickness without diffusion holes)	9.0	9.0	9.0	8.3	4.4 b
Plastic packaging (LDPE bags of 0.02 mm thickness with 8 diffusion holes)	9.0	9.0	9.0	9.0	9.0 a
Paper packaging - Brown paper bags of 0.01 mm thickness)	9.0	9.0	9.0	9.0	9.0 a
CV (%)	-	-	-	3.8	15.8

Means in the same column having a common letter or without letter designation are not significantly different from each other at 5% level, HSD

Chemical Characteristics

TSS, TA and pH. Soluble solid content is one of the most reliable parameters in judging fruit quality. Quality factors such as TSS, TA and visible quality (e.g. color, size and firmness) are prime considerations of consumers (Hoehn *et al.*, 2003; Lu, 2004). The total soluble solids act as a rough index of the amount of sugar present in fruits. Sugar constitutes 80-85 percent of soluble solids.

As gleaned from the study, no significant difference was observed on the TSS of tomato fruits as influenced by the systems of cultivation and MAP after storage (Table 6). However, tomato fruits in the open field had numerically higher TSS and TA of 3.9°Brix and 5.6%, respectively, than those under house-type protective structure that has only 3.6°Brix and 4.8%, respectively (Table 6). According to Naik *et al.* (1993), the total soluble solids increased during the ripening due to degradation of polysaccharides to simple sugars, thereby, causing a rise in TSS. Similarly, Pantastico (1975) mentioned that TSS usually increased with ripening as a result of starch hydrolysis. Some of the sugars, a major TSS component, are partially broken down to organic acid which correspondingly increased TA content. This behavior is manifested by fruits stored at ambient condition. A contrasting response was exhibited by MAP-stored fruits especially in sealed LDPE bags without diffusion holes wherein both TSS and TA contents decreased.

MAP significantly delayed the change in total soluble solids indicating a delay in ripening. Similar results were reported by Nakhasi *et al.* (1991) in tomatoes sealed in MAP bags. This was probably due to high water content maintained in the fruits as reflected by reduced weight loss, softening and decay at the same time (Table 3 and 4). In addition, airtight polyethylene bags have been known to reduce water loss and hydrolysis of polysaccharides which results in slight increase in TSS. The changes in TSS are directly correlated with hydrolytic changes in the starch concentration during the post-harvest period. These changes result in the conversion of starch to sugars, which is an important index of ripening process (Kays, 1991). Although TSS is known to increase during storage when insoluble starch is transformed into soluble solids, several studies have shown a decrease in TSS during storage (Martinsen and Schaare, 1998; McGlone and Kawano, 1998; Vela *et al.*, 2003). Numerous studies have reported that low O_2 storage suppresses TSS increase (Hoehnetal., 2003; Lopez, 2002). Likewise, most of the published literatures articulate that the soluble solids content decreased under cold storage as a result of slow respiration (Munoz *et al.*, 2006).

Physico-chemical changes in tomato (*Solanum lycopersicum* L.)

Table 6. Influence of cultivation system and MAP on TSS (°Brix), TA (%) and pH of tomato juicevar. 'Diamante Max' after 12 days of storage

4⊴°¥•Æ⟩	#®≠ℂ°¨£®°≤£¥≤ℂ¥ℂ≥°¥#) 6		
	433	4!	pH
! ÿSystems of cultivation			
Open field	ÿ	5.6 a	4.4
House-type protective structure	ÿ	4.8 b	4.5
"ÿ- ⊘§ℂ¶§!¥Ø≫®≤°£´ßℂÆ Χ ! 0Ψ			
7 ℂℛℚ⊔¥∞°£´ aging	ÿ	5.1 b	ÿ b
0¨°≥¥ℂ∞°£´°ßℂ∄B Χ $ 0%¢°ß≥Ø¶ ÿ mm thickness without diffusion holes)	ÿ	2.0 c	ÿ a
0¨°≥¥ℂ∞°£´°ßℂ∄B Χ $ 0%¢°ß≥Ø¶ ÿ mm thickness with 8 diffusion holes)	ÿ	5.1 b	ÿ b
0°∞≤∞°£´°ßℂ∄B - Brown paper bags of 0.01 mm thickness)	ÿ	8.6 a	ÿ b
#6 ⨯ Ψ	ÿ	13.1	ÿ

Means in the same column having a common letter or without letter designation are not significantly different from each other at 5% level, HSD and LSD

Acidity in fruits is an important factor in determining maturity. Titratable acidity gives the total or potential acidity, rather than indicates the number of free protons in any particular sample. The changes in organic acids during ripening viz., a rise in citrate, and fall in malate indicated a change in metabolism of citrate (Goodenough and Thomas, 1981). According to Bhattacharya (2004), acidity is often used as an indication of maturity which decreases during ripening of fruit. It has also been reported that during the ripening of tomatoes, malic acid disappears first, followed by citric acid (which result in reduction of amount of titrable acidity), suggesting the catabolism of citrate via malate (Mattoo *et al.*, 1975; Salunkhe and Desai, 1984).

The TA and pH of tomato fruits were significantly affected by the systems of cultivation and MAP. Although significant interactions were observed between systems of cultivation on TA and pH of tomato fruits, the trend of response was irregular. This result cannot simply justify the relationship between TA and pH wherein an increase in TA results to a significant decrease in pH. It could have been better that citric and malic acids were determined so as to partly contribute to the decrease in TA especially in those fruits obtained under protected cultivation and stored in MAP without diffusion holes. This was probably because the tomato fruits ripen faster regardless of the systems of cultivation under ambient

conditions. Conversely, the result of the present study considerably related to the findings of 'Chiripa' peaches stored in modified atmosphere wherein it has a higher titratable acidity (Brackmann *et al.*, 2000). Also, tomatoes packed in MAP maintained the titrable acidity and had a significantly higher acidity. Similar results were obtained by Tasdelen and Bayindirli (1998) and Nakhasi *et al.* (1991) in tomato and Escalona *et al.* (2003) in kholrabi. Additionally, Salunkhe *et al.* (1974) stated that the sugar of tomato fruit juices increases during ripening, whereas the acidity declines after the first appearance of yellow color in normal ripening. It then starts to increase again but thereafter the acidity starts to decrease, probably due to disappearance of citric acid. Disappearance of malic and citric acid during ripening process may be the main factor responsible for the reduction in titratable acidity during storage. The microorganisms may use citric acid as a carbon source, hence, resulting in reduction in the titratable acidity in infected fruits. De Souza *et al.* (1999) reported that the increment of titratable acidity is caused by the gaseous conditions (elevation of CO_2 concentration and reduction of O_2) during storage. These can affect the glycolytic enzyme system, resulting in a build-up of acids.

On the other hand, Wills *et al.* (1981) mentioned that the amount of organic acids usually decreases during maturity because organic acids are substrates of respiration. In general, MAP increased the TA contents resulting to significant decrease in pH except for tomato fruits stored in LDPE bags without diffusion holes which has a pH of 4.8 that was significantly higher than other treatments (Table 6). This may be due to the presence of microorganisms through condensation which is a common problem with MAP; hence, a slightly change in pH. According to Huber and O'Donoghue (1993), Chun and Huber (1998), and Almeida and Huber (1999) that the apoplastic environment, namely its pH and mineral composition, may affect the catalytic activity of cell wall enzymes. It is evident that the apoplastic pH of tomato fruit decreases from pH 6.7 in mature-green fruit to 4.4 at the ripe stage. The acidification of the apoplast over the pH range can provide a mechanism for the regulation of the catalytic activity of cell wall enzymes (Almeida and Huber, 1999).

Lycopene, dry matter content and total sugar. The systems of cultivation seem to have no significant influence on the lycopene content of tomato fruits due to high CV (%) (Table 7). In contrast, a significant difference was observed in the lycopene content of tomato fruits under MAP during storage. It was observed that the control had the highest lycopene content which was significantly higher than those tomato fruits

packed with LDPE without diffusion holes. However, it was comparable to fruits that were sealed in paper bags and LDPE bags with diffusion holes. The result of the present study shows that MAP maintained chlorophyll content in the fruits. This implies that MAP decreased the metabolic processes responsible for both chlorophyll degradation and lycopene synthesis or any process that may facilitate unmasking of preexisting lycopene. Kidd and West (1930) observed that the color change in tomato fruits from green to red, indicative of ripening could be retarded by high carbon dioxide, low oxygen or a suitable combination of these gases. The increase in the concentrations of carbon dioxide and ethylene is in agreement with the results reported by Nakhasi *et al.* (1991). The increased carbon dioxide concentration may have prevented accumulation of higher levels of ethylene, and also counteracted the biological activity of ethylene in enhancing chlorophyll degradation which has been noted in those tomato fruits under MAP storage. Although similar results were noted from MAP-stored fruits sealed in LDPE bags without diffusion holes, its lowest value of 2.2 mg/kg might be due to microbial contamination which also affects the ripening process and chlorophyll degradation of the fruit and consequently leads to higher variations.

Table 7. Influence of cultivation system and MAP on lycopene (mg/kg), dry matter (%) and total sugar (%) of tomato fruitsvar. 'Diamante Max' after 12 days of storage

4◁◆°¥•Æ≥	#®•≠℃°¨£®°≤£¥◁℃¥◁>°¥#) □		
	Lycopene	$≤π≠°¥≤	4Ø¥¨≥μß°≤
! ỳSystems of cultivation			
Open field	□ỳ□	□ỳ□	8.1
House-type protective structure	□ỳ□	□ỳ□	7.7
"ỳ- Ø§¶⊙§ !¥≠Ø≫®≤ 0°£´°ß⨌B X !0Ψ			
7 ⨌RQμ¥∞°£´°ß⨌B	26.9 a	5.2 a	□ỳ□
0¨°≥¥℃∞°£´°ß⨌B X $0%¢°ß≥Ø⫿□ỳ□≠≠ thickness without diffusion holes)	2.2 b	3.6 b	2.2
0¨°≥¥℃∞°£´°ß⨌B X $0%¢°ß≥Ø⫿0.02 mm thickness with 8 diffusion holes)	19.1 a	4.4 ab	7.4
0°∞•≤∞°£´°ß⨌B - Brown paper bags of 0.01 mm thickness)	17.7 ab	4.7 ab	□ỳ□
#6 ✕▸Ψ	42.1	11.7	50.0

Means in the same column having common letters or without letter designation are not significantly different from each other at 5% level, HSD and LSD

Likewise, fruits were still green upon termination of the study indicating that lycopene was not fully synthesized yet. On the other hand, Yang and Chinnan (1987) found that color development (i.e. loss of

chlorophyll) is delayed by storing tomato fruits under CA. MAP has also been shown to delay color change in tomato fruits although these treatments were in combination with low temperature (Nakhasi *et al*., 1991 and Yang and Chinnan, 1987).

According to Pantastico (1975), chlorophyll degradation and increased lycopene synthesis results in the characteristic color development during ripening in tomatoes. Storing the fruits in modified atmosphere packs significantly delayed the lycopene biosynthesis which is in agreement with the present study. This can be attributed to delay in ripening due to reduced respiration rates of these packed fruits. Similar results have been reported by Gabriel et al*.* (1999) and Geeson *et al.*(1985) in tomato and Kerbel *et al.*(1988) in pear fruits.

Furthermore, the percent dry matter was not significantly influenced by the systems of cultivation (Table 7). Comparable results were observed among treatments under MAP storage. However, tomato fruits in the open tray were found to have the highest dry matter content of 5.2% whereas the lowest of 3.6% was found in LDPE bags without diffusion holes. This might be due to the higher rate of transpiration as well as high RH and lower concentration of CO_2 and higher concentration of O_2 during the 12 days storage at ambient conditions which contributed to the faster moisture loss that consequently increased the dry matter content of the exposed tomato fruits.

Dry matter loss is attributable to tissue respiration and carbohydrate metabolism. With respect to the effect of MAP-stored fruits especially in sealed LDPE bags without diffusion holes, McConnel *et al.* (2005) reported that limiting O_2 reduces respiration rate and depletion of carbohydrates. As what was observed from this study the presence of microbial growth is one of the factors limiting the storage of tomato fruits, enhances decay and reduces weight loss thereby reducing the dry matter content of the fruits.

Moreover, total sugar is an important factor for determining the quality of the tomato fruits. The flavor of a product depends on total sugar percentage. As presented in Table 7, the results revealed that there was no significant effect on the total sugar content of tomato fruits by the systems of cultivation as well as by the method of storage. Although statistically no significant difference was reflected on the total sugar content by the method of storage, it was noted that MAP-stored fruits especially sealed in LDPE bags without diffusion holes were numerically low among other treatments whereas the control obtained the highest percentage of total sugar content after 12 days of storage. The high CV (%) was mainly due to

the presence of trace amount that was obtained from the analysis of tomato fruits stored in MAP without diffusion holes due to microorganisms contamination which resulted to rotting. On the other hand, Sammi and Masud (2007) found that tomato fruits exposed to ambient condition showed highest amount of sugars; however, this gradually decreased as the ripening advanced which was consistent with the result of the present study. The total sugar content of tomato fruits increased significantly with change of maturity during storage under ambient conditions.

CONCLUSION

The system of cultivation did not significantly affect the postharvest behavior of tomato fruits in terms of peel color development, fruit firmness, weight loss, decay incidence, visual quality rating and shelf life, total soluble solids, titrable acidity, pH, lycopene, dry matter, and total sugar. MAP storage significantly influenced some of the storage parameters evaluated. Paper bags and polybags with eight diffusion holes slightly delayed ripening, effectively reduced weight loss, minimized decay incidence, and maintained higher VQR throughout the 12-day of storage than LDPE bags without diffusion holes.

Protected cultivation and MAP-stored fruits both in paper bags and polybags with diffusion holes were effective in maintaining the physico-chemical qualities and extend the storage life of tomato fruits.

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REFERENCES

ALI, Z.M., CHIN, L., MARIMUTHU, M., and LAZAN, H. 2004.Low temperature storage and modified atmosphere packaging on carambola fruit and their effects on ripening related texture changes, wall modification and chilling injury symptoms. *Postharvest Biology and Technology* **33:** 181-192.

ALMEIDA, D.P.F. and D.J. HUBER.1999. Apoplastic pH and inorganic levels in tomato fruit: a potential means for regulation of cell wall metabolism during ripening. *Physiol. Plant.* 105, 506–512.

ALSADON, A. A., A. M. ALHAMDAN, and M. A. OBIED. 2004. Effect of Plastic and Paper Packaging on Tomato Fruits Stored at Different Temperatures and High Relative Humidity; I. *Chemical Properties, Quality Attributes and Shelf Life*. International Symposium on Greenhouses, Environmental Controls and In-house Mechanization for Crop Production in the Tropics and Sub-Tropics.Equatorial Hill Resort, Cameron Highlands Pahang, Malaysia.

AMBI, F. G. 1992. *Performance evaluation of a box-type evaporative cooler in the storage of tomato fruits*. BS Thesis. Visca, Baybay, Leyte.

APILAR, E.G. 2002. *Horticultural and physiological responses of two tomato* (*Lycopersiconesculentum* Mill.) *varieties to open field and protected cultivation*. PhD. Dissertation. LSU, Visca, Baybay, Leyte.

ARTES, F. and A.J. ESCRICHE.1994. Intermittent warming reduces chilling injury and decay of tomato fruit. *J. Food Sci.* **59:** 1053-1056.

BABITHA, K.C. 2006. *Physiological basis of extending postharvest shelf life in tomato*.

BAUTISTA, O.K. and E.B. ESGUERRA.2007. *Postproduction technologies of fruits and vegetables*. Southeast Asia. 480 pp.

BEAUDRY, R.M., A.C. CAMERON, A. SHIRAZI, and D.L. DOSTAL-LANGE. 1992. Modified-atmosphere packaging of blueberry fruit: Effect of temperature on package O_2 and CO_2. *J. Amer. Soc. Hort. Sci.* **117:**436-441.

BHATTACHARYA, G. 2004.*Served Fresh.Spotlight.Times Food Processing Journal*.

BRACKMANN, A., A.J. WACLAWOVSKY, S.M. MAZARO, and M. CERETTA. 2000. Storage of 'chiripa' peach in controlled atmosphere. *Revista Brasileira de Agrociencia*, **6 (3):** 209-212.

BRUMMELL, D.A. and M.H. HARPSTER. 2001. Cell wall metabolism in fruits oftening and quality and its manipulation in transgenic plants. *Plant Molecular Biology* **47:** 311–340.

CAGAMPANG, G.B. and F.M. RODRIGUEZ. 1980. *Methods of Analysis for Screening Crops of Appropriate Qualities*. Analytical Services Laboratory, Institute of Plant Breeding, University of the Philippines at Los Baños.

CAÑETE, I. V. 1993. *Postharvest characteristics of tomato fruits stored in modified evaporative coolers*. BS Thesis. Visca, Baybay, Leyte.

CHENG, T.S. and R.L. SHEWFELT. 1988. Effect of chilling exposure of tomatoes during subsequent ripening. *J. Food Sci.* **53:** 1160-1162.

CHUN, J.P. and D.J.HUBER. 1998. Polygalacturonase-mediated solubilization and depolymerization of pectic polymers in tomato fruit cell walls. Regulation by pH and ionic conditions. *Plant Physiol.* **117:** 1293–1299.

DE-SOUZA, A.L.B., S.D.Q. SCALON, M.I.F. CHITARRA and A.B. CHITARRA. 1999. Post-harvest application of CaCl2 in strawberry fruits (*Dragariaananassa Dutch* c.v. Sequóia). Evaluation of fruit quality and post-harvest life.*Ciênc.Eagrotec, Lavras*. **23(4)**: 841-848.

DORIA, M. T. 1994. *Control of tomato* (*Lycopersiconesculentum* Mill.) *fruit ripening and decay during storage under evaporative cooling condition*. BS Thesis. Visca, Baybay, Leyte.

ESCALONA, V.H., E. AGUAYO, AND F. ARTES. 2003. Quality and physiological changes of fresh-cut kohlrabi. *HortScience* **38 (6)**: 1148-1152.

GABRIEL, O.S., D.T. GUSTAVO, and A.F. ADELA. 1999. Controlled atmosphere storage of tomato fruit: low oxygen or elevated carbon dioxide levels alter galactosidase activity and inhibit exogenous ethylene action. *Journal of the Science of Food and Agriculture* **79:** 1065-1070.

GARNAUD, J.P. 1988. Protected cultivation — yesterday, today and tomorrow. *Proceedings, Conferences on 'Plastics in the Nineties'*.British Agricultural and Horticultural Plastics Association.

GEESON, J.D., K.M. BROWNE, K. MADDISON, J. SHEPHERD, and F. GUARALDI. 1985. Modified atmosphere packaging to extend the shelf life of tomatoes. *Journal of Food Technology* **20:** 339-349.

GOODENOUGH, P.W. AND T.H.THOMAS. 1981. Biochemical changes in tomatoes stored in modified gas atmospheres. I. *Sugars and acids. Annals of Applied Biology* **98:**507-515.

GONG, S. and K.A. COREY. 1994. Predicting steady-state oxygen concentrations in modified atmosphere packages of tomatoes. *J. Amer. Soc. Hort. Sci.* **119:** 546-550.

GRIERSON, D. and G.A.TUCKER.1983. Timing of Ethylene and Polygalacturonase Synthesis in Relation to the Control of Tomato Fruit Ripening. *Planta* **157:**174-179.

GRIERSON, W. 1969. Consumer packaging of citrus fruits. *Proceedings of 1st Intl. Citrus Symp.* **3:**1389-1401.

HARDENBURG, R.E. 1951. Further studies on moisture losses of vegetables packaged in transparent films and their effect on shelf life. *Proc. Amer. Soc. Hort. Sci.* **57:**277-284.

HARKER, F.R., R.J. REDGWELL, I.C. HALLETT, S.H. MURRAY, and G. CARTER. 1997. Texture of fresh fruit. *Horticultural Reviews* **20:** 121–224.

HOEHN E., F. GASSER, B. GUGGENBUHL, and U. KUNSCH. 2003. Efficacy of instrumental measurements for determination of minimum requirements of firmness, soluble solids, and acidity of several apple varieties in comparison to consumer expectations. *Posthar. Biol. Technol.* **27:** 27-37.

HUBER, D.J. and E.M. O'DONOGHUE. 1993. Polyuronides in avocado (*Perseaamericana*) and tomato (*Lycopersiconesculentum*) fruits exhibit markedlydifferent patterns of molecular weight downshifts during ripening. *PlantPhysiol.* **102:** 473–480.

HUBER, D.J. 1983. The role of cell wall hydrolases in fruit softening. *Horticultural Review* **5:** 169-219.

KADER, A.A. and R.S. ROLLE. 2004. The role of post-harvest management in assuring the quality and safety of horticultural produce. *FAO Agricultural Services Bulletin* 152. Rome, Italy. pp. 1.

KADER, A.A., D. ZAGORY, and E.L. KERBEL. 1989. Modified atmosphere packaging of fruits and vegetables. CRC *Crit. Rev. Food Sci. Nutrit.* **28:** 1-30.

KADER, A.A., L.L. MORRI, M.A. STEVENS, and M. ALBRIGHT-HOLTON. 1978. Composition and flavour quality of fresh market tomatoes as influenced by some postharvest handling procedures. *J. Amer. Soc. Hort. Sci.*; **103:** 6-13.

KAYS, S.J. 1991. *Post-harvest Phys. of Perishable Plant Products.* Vas Nostrand Rein Hold Book, AVI Publishing Co. pp. 149-316.

KERBEL, E.L., A.A. KADER, and R.J. ROMANI. 1988. Effects of elevated CO_2 concentrations on glycolysis in intact 'Bartlett' pear fruit. *Plant Physiology* **86:** 1205-1209.

KIDD, F. and C. WEST. 1930. The gas storage of fruit. II. Optimum temperatures and atmospheres. *J. Pomol. Hort. Sci.* **8:** 67-83.

KIM, J.H. 1990. *Possible approaches for diversification of cropping patterns for the protected cultivation of horticultural crops*. Rural Development Administration. pp. 46-56.

KLIEWER, M.W. and L. A. LIDER. 1968. Influence of cluster exposure to the sun on the composition of Thompson seedless fruit. Amer. J. Enol. Viticul **19:** 175 – 184.

LOPEZ, V.M.G. 2002. Inhibition of surface browning, cut avocado. *J. of Food Quality* **26:** 265-384.

LU, R. 2004. Multispectral imaging for predicting firmness and soluble solids content of apple fruit. *Postharvest Biology and Technology* **31:** 147-157.

MANTE, M. A. 1992. Postharvest characteristics of sweet pepper (*Capsicum anuum* L.) *fruits as influenced by harvest maturity and storage condition*. BS Thesis. Visca, Baybay, Leyte

MARTINSEN, P. and P. SCHAARE. 1998. Measuring soluble solids distribution in kiwifruitusing near-infrared imaging spectroscopy. *Postharvest Biology andTechnology* 14: 271-281.

MATHOOKO, F.M. 1995. *Studies on the biochemical and physiological responses of fruits and vegetables to treatment with elevated levels of carbon dioxide*. Ph.D. Thesis, Okayama University, Okayama, Japan.

MATOO, A.K., T. MURATA, E.B. PANTASTICO, K. CHACHIN, and C.T. PHAN. 1975. Chemical changes during ripening and senescence. In: *Post Harvest Utilization of Fruits and Vegetables*, The AVI Publication Co., West Port, Connecticut, USA, pp.78.

MCCONNELL R.Y., V.D. TRUONG1, W.M. WALTER JR., and R.F. MCFEETERS. 2005. Physical, chemical and microbial changes in shredded sweet potatoes.

MCGLONE, V.A. and S. KAWANO. 1998. Firmness, dry-matter and soluble-solids assessment of postharvest kiwi fruit by NIR spectroscopy. *Postharvest Biology and Technology* 13: 131-141.

MUNOZ, P.H., E. ALMENAR, M. OCIO, and R. GAVARA. 2006. Effect of calcium dips and chitosan coating on post-harvest life of strawberries (*Fragariaananassa*), *J. Postharvest Biology and Technology*39: 247-253.

NAIK, D.M., V.G. MULEKAR, C.G. CHANDEL, and B.M. KAPSE.1993. Effect of prepackaging on physico-chemical changes in tomato (*Lycopersiconesculentum* Mill.) during storage. *Indian Food Packer*, July-August, pp. 9-13.

NAKHASI, S., D. SCHLIMME, and T. SOLOMOS. 1991. Storage potential of tomatoes harvested at the breaker stage using modified atmosphere packaging.*J. Food Sci*. 56: 55-59.

ONWUZULU, O.C., T.N. PRABHA, and S. RANGANNA.1995, Modified atmosphere storage of ripening tomatoes : Effect on quality and metabolism of 14C glucose and 14C – acetate. *Tropical Science*, 35: 251-258.

PANTASTICO, E.B. 1975, In: *Post harvest physiology, handling and utilization of tropical and subtropical fruits and vegetables.* West Port, CT: A VI, pp. 86-102.

PILNIK, W. and A.G.J. VORAGEN. 1970. Pectic substances on others uronides. In: *A.C. Hulme (ed). The Biochemistry of Fruits and Their Products.* Academic Press, London.

REYES, S. Q. 1990. *Efficacy of different evaporative cooling techniques in delaying the postharvest deterioration of pechay*. BS. Thesis. Visca, Baybay, Leyte

ROSE, J.K.C., K.A. HADFIELD, J.M. LABAVITCH, A.B. BENNETT, 1998. Temporal sequence of cell wall disassembly in rapidly ripening melon fruit. *PlantPhysiol*. 117: 345–361.

SALUNKHE, D. K. and B. B. DESAI. 1984. *Post-Harvest Biotechnology of Vegetables.* Vol. 1. CRC Press, Inc. Boca Raton, Florida, US. pp 55-82.

SALUNKHE, D. K., S. J. YADHEV, AND M. H. YU. 1974. Quality and nutritional composition of tomato fruit as influenced by certain biochemical and physiological changes. *Qual. Plant. Plant Foods Hum. Nutr*. 24(1/2): 85. As cited by Salunkhe, D. K. and B. B. Desai. 1984. Post-Harvest Biotechnology of Vegetables. Vol. 1. CRC Press, Inc. Boca Raton, Florida, US. 55-82 pp.

SAMMI, S., and T. MASUD. 2007. Effect of different packaging systems on storage life and quality of tomato (*Lycopersiconesculentum*var. Rio Grande) during different ripening stages. *Internet Journal of Food Safety*, Vol.9, p. 37-44.

SERGENT, S.A. and C.L. MORETTI. 2004. Tomato.

SUBERE, M.V.Q. 1997. *Effect of fruit storage volume and decay control treatments on the postharvest life of tomatoes stored in simple evaporative coolers.* Undergrad. Thesis. Visayas State College of Agriculture. Visca, Baybay, Leyte. 10 pp.

TASDELEN, O. AND L. BAYINDIRLI.1998, Controlled atmosphere storage and edible coating effects on storage life and quality of tomatoes. *Journal of Food Processing Preservation* 22: 303-320.

THAKUR, A.K. and M.PANDEY. 1999. Varietal variation in cell wall softening enzymes during tomato (*Lycopersiconesculentum*Mill.) fruit ripening. *Indian Journal of PlantPhysiology* **4 (3)**: 221-223.

THEMMAN, A.P.N., G. TUCKER, and D. GRIERSON.1982. Degradation of Isolated Tomato Cell Walls by Purified Polygalacturonase in Vitro. *Plant Physiol.* 69: 122-124.

VELA, G., D.M. LEON, H.S. GARCIA, and J.D.C. UNIDA. 2003. Polyphenoloxidase activity during ripening and chilling stress in 'Manila' mangoes.*J. Hort. Sci. Biotechnol.* 78: 104-107.

VITUG, V. 1989. Tomato: Good commercial crop.*Agriscope* 3: 34-35.

WILLS, R.H.H., T.H. LEE, W.B. GRAHAM, and E.G. HALL. 1981. *Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables.* New South Wells Press, Kensington.

XUE, Y., Y. KUBO, and R. NAKAMURA.1996. Effects of humidity on ripening characteristics of banana fruit. *Nip. Sho.Kog.Kaishi.* 43: 541-545.

XUE, Y., Y. KUBO, A. INABA, and R. NAKAMURA. 1995. Effects of humidity on ripening and texture of banana fruit. *J. Japan. Soc. Hort. Sci.* 64: 657-664.

YANG, C.C. and M.S. CHINNAN. 1987. Computer modeling of color development of tomatoes in modified atmosphere storage. *Trans. Amer. Soc. Agric. Eng.* 30: 548-553.

ZAGORY, D. and A.A. KADER .1988.Modified atmosphere packaging of fresh produce.*Food Technol.* 42: 70-77.