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RESPIRATION AND ETHYLENE PRODUCTION RATES OF CHILI PLUMS (*SPONDIAS PURPUREA* L) DURING STORAGE

Owen S. Graham, *Lynda D. Wickham, and Majeed Mohammed, Department of Food Production, The Faculty of Agriculture and Natural Sciences, The University of the West Indies, St. Augustine, Trinidad and Tobago W.I.*

ABSTRACT: The chili plum is found throughout the Caribbean and Central American regions and is consumed in the fresh and processed states. Respiration and ethylene production rates were determined in fruit harvested at three different stages of maturation (immature, mature-green and turning) when stored up to 14 days at 4-5°C, 9-10°C, 20-21°C and 30-31°C. In a second experiment (experiment two), respiration and ethylene production rates were again determined however in fruit harvested at six different stages of maturity (very immature, immature, mature-green, turning, half-ripe and full-ripe) when stored up to 9 days at 9-10°C and 20-21°C. At 9-10°C, respiration rates declined in all fruit within 2 days with half-ripe fruit having the highest respiration rates by day 3. From days 3-5, while respiration rates declined for half-ripe and turning fruit, it increased for very immature, immature and mature-green fruit, then declined. At 20-21°C, half-ripe fruit exhibited more pronounced climacteric peaks than mature-green and turning fruit. Half-ripe and turning fruit exhibited climacteric peaks of respiration after 3 days while mature-green fruit did so one day later. Fruit underwent the post-climacteric respiratory phase within 24 hours after attaining their climacteric peaks. Ethylene was only detected at 20-21°C with peak production rates coinciding with the post-climacteric phase for full-ripe and turning fruit. Respiration and ethylene production rates of the chili plum were typical of a climacteric fruit.

INTRODUCTION

The chili plum (*Spondias purpurea* L) is a popular fruit in the Caribbean and Central and South America regions. Common names include 'Moyo', 'Sta Roseno', and 'Jismoyo' among others (Barbeau, 1994). A member of the Anacardiaceae family, the tree normally grows to about 3-10 meters in height. The leaves are usually 2.5 - 6.5 cm long with 5 - 23 leaflets.

In the Caribbean, fruiting occurs between the months of September to November (Adams, 1972). This smooth and shiny ellipsoid drupe measures 2.5 – 4.0 cm in length and 1.5 - 2.5 cm in diameter and ripens rapidly (2-3 days under ambient conditions) from the mature-green stage (Barbeau, 1994).

Although this fruit is widely consumed in both the fresh and processed states, there is an increasing demand for the fruit at both the immature and mature stages for use in processed forms that have great potential for the export market. There is generally a lack of published information on the postharvest behaviour of this fruit. While studies have been reported on freshly harvested chili plums pertaining to total soluble solids and total titratable acids content (Pilgrim, 1994) there are no published data on important physiological features such as respiratory behaviour and ethylene production rates during the storage of the fruit. Such information is essential if effective postharvest handling and storage techniques are to be established for this fruit. Although it is not possible to improve the quality of produce after harvest, effective postharvest handling and storage techniques can be used to reduce the rate of the onset of undesirable changes such as loss of cellular integrity, excessive softening, the development of off-flavours and odours which result from senescence and fruit decay.

Accordingly a study was conducted to examine the respiratory behaviour, ethylene production rates, chilling sensitivity and organoleptic changes in chili plums during storage at refrigerated and non-refrigerated temperatures.

MATERIALS AND METHODS

Chili plums were hand-harvested and graded into immature (M1), mature-green (M2) and slightly turning or breaker (M3) according to size, colour and apparent maturity. Fruit were placed in single-ply cardboard boxes and transported to the laboratory in the Department of Food Production at the University of the West Indies, St. Augustine within three (3) hours of harvest. Fruit were washed in tap water then dipped for 2 minutes in 200 ppm, sodium hypochlorite solution to control surface pathogens. Fruit were spread in a single layer and left for 20 minutes in an air-conditioned room (20-21^{0}C, 70-75 % relative humidity) until surface moisture had evaporated.

In the first study (experiment one) blemish-free fruit were stored at 4–5^{0}C (T1), 9–10^{0}C (T2), 20–21^{0}C (T3) and 30–31^{0}C (T4). Respiratory measurements, ethylene production rates, percentage marketable fruit, sensory quality, chilling injury and decay were assessed at harvest, and followed by daily assessments for up to 15 days.

Fruit respiration was determined by the use of a Finnigan gas chromatograph Model # 9001; (Austin, Texas) which was used to measure simultaneous carbon dioxide (CO_2) and ethylene (C_2H_4) production rates daily. Ethylene was measured using a Flame ionization detector (FID) while carbon dioxide was measured using a Thermal conductivity detector (TCD). Fruit were weighed and incubated in 1-litre air-tight high density jars for 2 hours. Approximately 0.3 ml of the atmosphere in the jars was withdrawn with a 1.0 ml syringe and injected through a rubber septum in the gas chromatograph with helium as the carrier gas with a flow rate of 25 ml/min. The flow rates of hydrogen and air were 15 ml/min and 175 ml/min respectively. A megabore column of 0.53 mm and 30 m in length were used. The levels of both CO_2 and C_2H_4 were measured and calculated against standard gas mixtures. The lowest concentration or rate of carbon dioxide production that could be detected was 0.01% whereas that of ethylene was 1μg/ml.

Comparative sensory evaluations for flavour were performed using a 20 member semi-trained panel. Panelists used a modified hedonic scale of 1-5 with 1 representing unacceptable, 2-slightly acceptable, 3-acceptable (limit), 4-very acceptable and 5 extremely acceptable (Ranganna, 1986).

Chilling injury (CI) based on external damage was scored on each fruit using a subjective scale: 1 = no damage, 2 = slight damage, 3 = medium damage, 4 = severe damage, 5 = very severe damage. The CI index was calculated according to the formula used by Pesis *et al.,* (1994).

$$\text{CI Index} = \frac{\sum_{0}^{5} (\text{injury level}) \times (\text{number of fruit at this level})}{\text{total number of fruit}}$$

Severity of decay was rated on each fruit using the following subjective scale 1=no decay, 2=slight, 3=moderate, 4=severe and 5=complete breakdown. The incidence was reported as the percentage of fruit exhibiting a severity rating >1. Marketable quality was rated for each fruit using the following subjective scale 1= very poor quality, 2= poor quality, 3= moderate quality, 4= good quality and 5= excellent. The number of fruit with a rating of 3 and above were used to calculate percentage marketable fruit.

During a second study (experiment two) fruit were harvested, graded, transported to the laboratory and washed as described previously. However, based on observations of very severe chilling injury during storage at 4-5^{0}C and extensive decay at 30-31^{0}C during the first study, fruit were stored at intermediate temperatures, (9-10^{0}C and 20-21^{0}C). Additionally during this study six maturity stages were used. Fruit were classified as (M1) very immature, (M2) immature, (M3) mature-green, (M4) slightly turning or breaker, (M5) half-ripe and (M6) full-ripe, according to size, colour and apparent maturity.

Respiratory measurements, ethylene production rates, sensory evaluation and decay were assessed again at harvest (day 0) and subsequently at 1 day intervals up to 8 days by the methods previously described.

Both experiments were of a completely randomized design with a factorial arrangement of variables. Each treatment was replicated three times with each replicate consisting of 10 fruit. Data were subjected to Analysis of Variance, using GENSTAT (Genstat 5.0, 1995) and the levels of significance determined by the F-test. Comparison of the means using the least significant difference (LSD) method was done at the 5% level, where applicable.

RESULTS

Percentage marketable fruit

Irrespective of storage temperature, the quality of chili plum fruit declined over time ($P<0.001$) resulting in comparative reductions in percentage marketable fruit. Increased softening and respiration rates as well as external discolourations paralleled reductions in quality and percentage marketable fruit. Less mature fruit generally had higher rates of quality deterioration, while storage of fruit at 20-21°C, 9-10°C and 4-5°C delayed quality deterioration compared to fruit stored at ambient temperature (Figures 1A-D). There were no marketable turning fruit beyond 9 and 11 days at 4-5°C and 9-10°C respectively due to excessive fruit softening. After 15 days at 9-10°C, 85% of mature-green fruit appeared marketable whereas only 42% of immature fruit appeared marketable (Figures 1A-B). However, despite this, all fruit stored for 15 days at this temperature developed chilling injury. Upon transfer to 20-21°C for 2 days chilling injury was manifested in mature-green fruit as tiny pits that coalesced into larger depressed areas with a definite brown discolouration.

Respiration (CO_2) and ethylene (C_2H_4) production rates

In experiment one, the respiration rates for fruit at all three maturity stages stored at 4-5°C and 9-10°C, remained very low throughout storage (Figures 2A-B). Generally CO_2 production rates increased ($P<0.001$) over time in fruit stored at 20-21°C and 30-31°C (Figures 2C-D). At these temperatures, ripening occurred in mature-green and turning fruit where as senescence was observed in immature fruit.
In experiment two, CO_2 production rates declined ($P<0.001$) in all fruit after 2 days at 9-10°C with full-ripe fruit having higher CO_2 production rates thereafter than immature, mature-green, turning and half-ripe fruit (Figure 3A). Between days 3-5, CO_2 production rates increased for immature and mature-green fruit, but declined for turning and half-ripe fruit (Figure 3A). At 20-21°C, immature fruit and half-ripe fruit exhibited a more pronounced climacteric peak than mature-green (M3) and turning fruit (Figure 3B). The respiratory climacteric observed in very immature to half-ripe fruit was notably absent in full-ripe as there were ($P>0.001$) reductions in CO_2 production rates for full-ripe fruit throughout this study (Figure 3B). In experiment two, C_2H_4 production rates also increased ($P<0.001$) for immature, mature-green and turning fruit, peaking between 3-5 days of storage at 20-21°C followed by a rapid decline (Figure 3C). Peak C_2H_4 production rates preceded peak CO_2 production rates for immature and turning fruit (Figures 3B-C).

Flavour

Organoleptic evaluations indicated that only mature-green and ripened fruit were acceptable in terms of flavour throughout, during both experiments (Figures 4A-D).

Chilling injury (CI)

Chilling injury (pitting) developed in all fruit stored at 4-5°C and 9-10°C after 4 days (experiment one). Symptoms were most evident in immature fruit and least in turning fruit (Figures 4E-F). Mature-green fruit stored at 9-10°C for 15 days followed by 2 days at 20-21°C developed moderate chilling injury (Figure 4E). Immature fruit, on the other hand, showed symptoms of severe chilling injury (Figures 1B and 4F). Mature-green fruit stored continuously for 15 days at 4-5°C, then transferred to 20-21°C for 1 day, exhibited severe chilling injury symptoms with tiny pits that coalesced into larger depressed areas and had a definite brown discolouration. The same occurred in mature-green fruit stored at 9-10°C for 15 days upon transfer at 20-21°C for 2 days.

Decay

Storage of fruit at 9-10°C greatly reduced pathological decay (Tables 1 & 2). All fruit stored at 20-21°C and 30-31°C were decayed by day 8 and decay was generally more prevalent and rapid in mature than immature fruit (Tables 1 & 2).

DISCUSSION

During this study, storage of chili plum fruit at reduced temperatures (4-5°C and 9-10°C) resulted in the development of chilling injury and loss of marketability. While mature-green fruit stored at 9–10°C for 15 days followed by 2 days at 20-21°C had symptoms of moderate chilling injury, immature fruit had symptoms of severe chilling injury and there were no marketable turning fruit beyond 9 and 11 days at 4-5°C and 9-10°C respectively because of excessive softening. Mature-green fruit stored continuously for 15 days at 4-5°C upon transfer at 20-21°C for 1 day developed severe chilling injury symptoms such as extensive brown discolourations.

Storage of fruit at 4-5°C and 9-10°C inhibited ripening and associated changes, thereby reducing the rates of respiration and C_2H_4 production and also pathological decay. However, during storage at 20-21°C and 30-31°C fruit ripening occurred with CO_2 production rates increasing two to three-fold over time in mature fruit, identifying the chili plum as a climacteric fruit. The respiratory pattern of the chili plum was typical of a climacteric fruit. Half-ripe fruit exhibited a more pronounced climacteric peak than mature-green and turning fruit. Similar reports were made by Roux (1940) with temperate plums (*Prunus* spp). A similar trend to that of CO_2 production rates was observed with C_2H_4 production rates in the chili plums stored at 20-21°C and 30-31°C as C_2H_4 production rates also increased over time due to the onset of ripening in mature fruit and senescence in immature fruit.

Organoleptic evaluations generally indicated that only mature-green and ripened fruit were acceptable in terms of flavour. There were no marketable fruit after 8 days for all 3 maturity stages stored at 20-21°C and 30-31°C as a result of extensive decay. Decay was generally more prevalent and rapid in mature plums than immature. A reduction of natural resistance of tissues to pathogen attack with increasing maturity has been previously reported by Ingham (1973).

Based on the findings of this study, it was concluded that the chili plum is a climacteric fruit and that it is highly susceptible to chilling injury.

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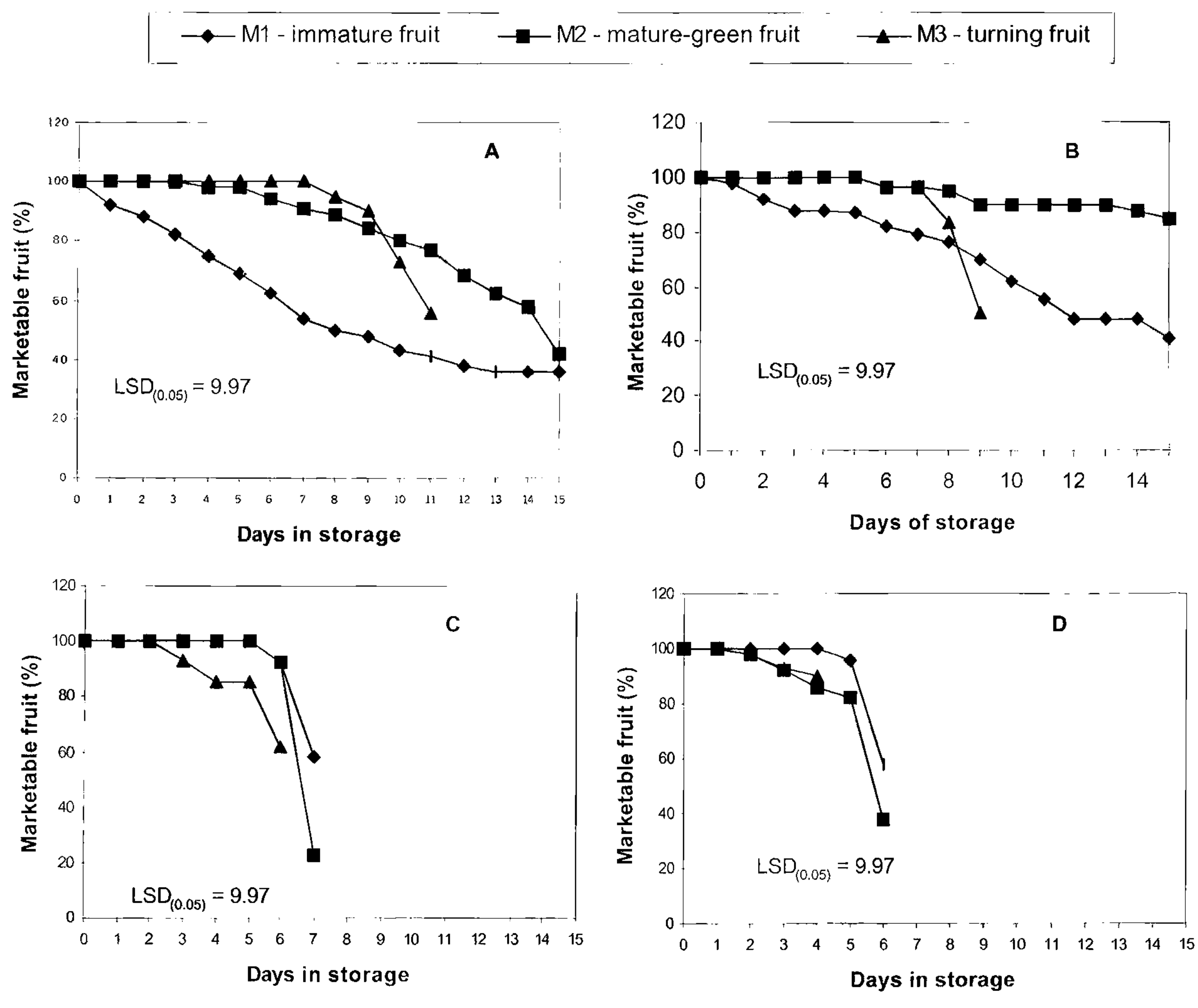

Figure 1. Percentage marketable chili plum fruit during storage for 15 days.
(A) Fruit stored at 4-5°C, (B) fruit stored at 9-10°C, (C.) fruit stored at 20-21°C and (D) fruit stored at 30-31°C. Level of significance (P<0.001).

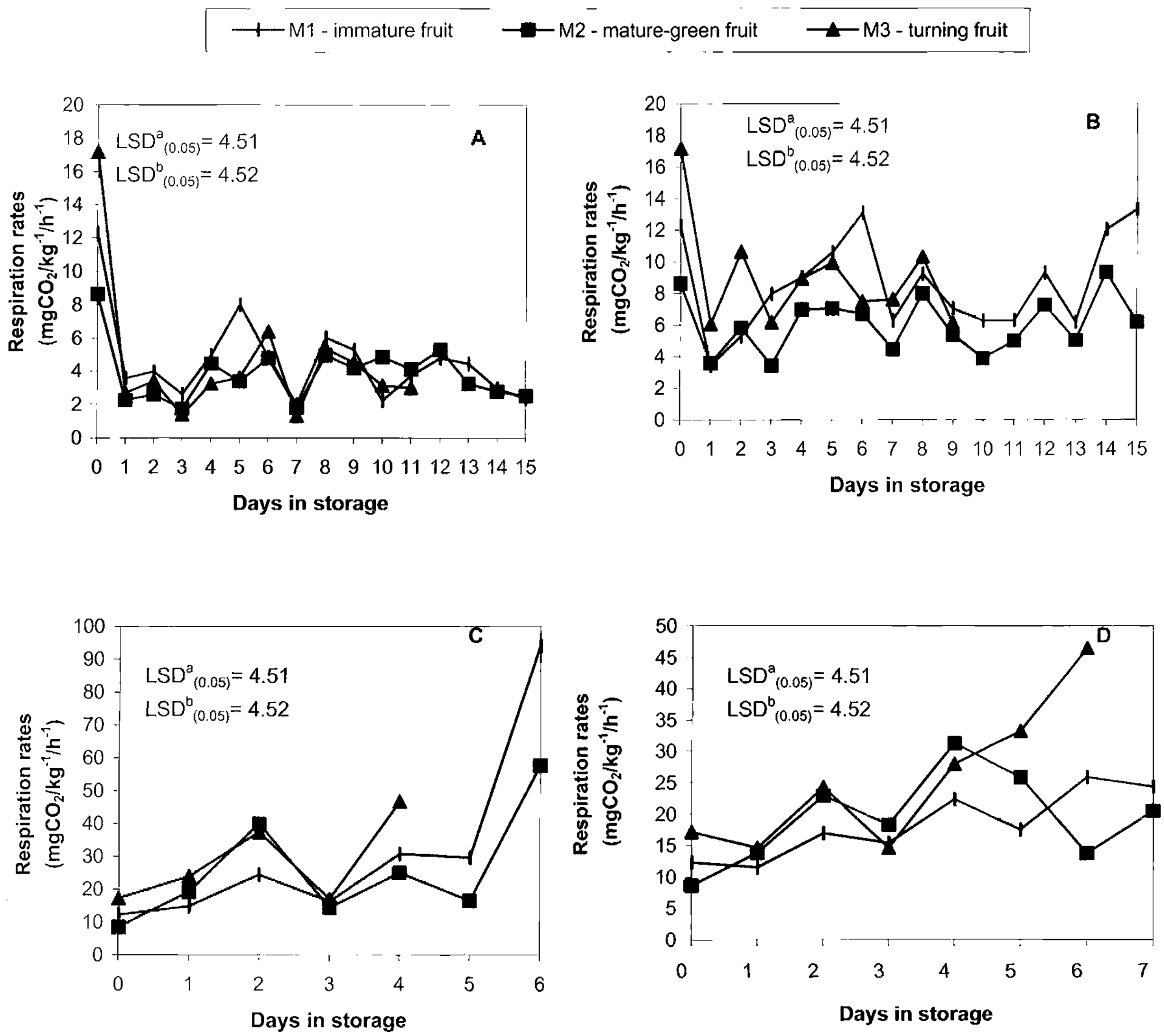

Figure 2. Changes in the respiration rates of chili plums during storage at different temperatures. (A) Fruit stored at 4-5°C, (B) fruit stored at 9-10°C, (C.) fruit stored at 20-21°C and (D) fruit stored at 30-31°C. LSD: over time[a] while across maturity stages and temperatures on the same day[b]. Level of significance (P<0.001).

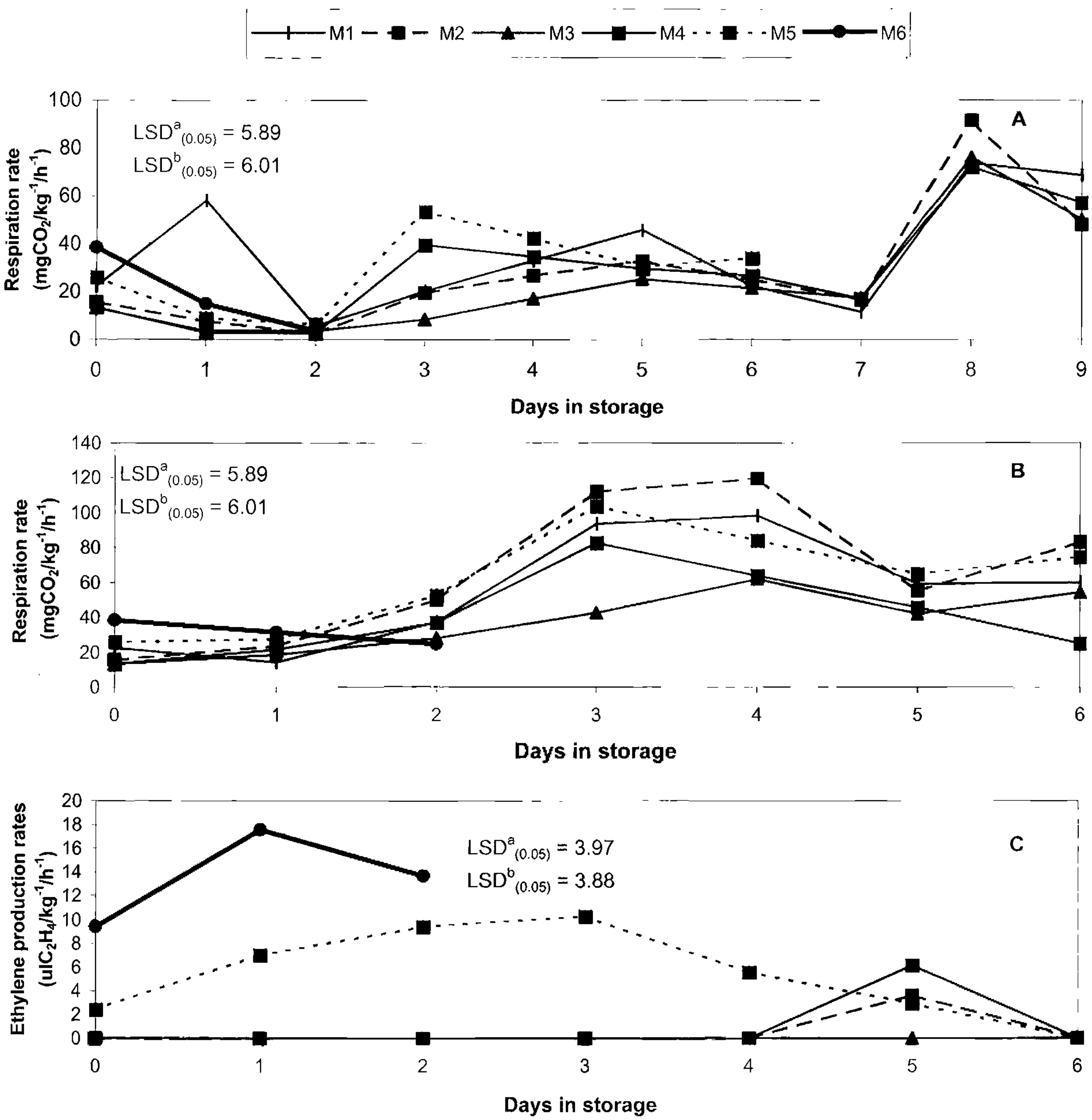

Figure 3. Changes in the respiration and ethylene production rates of chili plum fruit during storage. (A) Fruit stored at 9-10°C, (B) fruit stored at 20-21°C and (C.) fruit stored at 20-21°C. LSD: over time[a] while across maturity stages and temperatures on the same day[b]. M1= very immature fruit, M2= immature fruit, M3= mature-green fruit, M4= turning fruit, M5 = half-ripe fruit and M6 = full-ripe fruit. Levels of significance were ($P<0.001$) for respiration and ethylene production rates respectively.

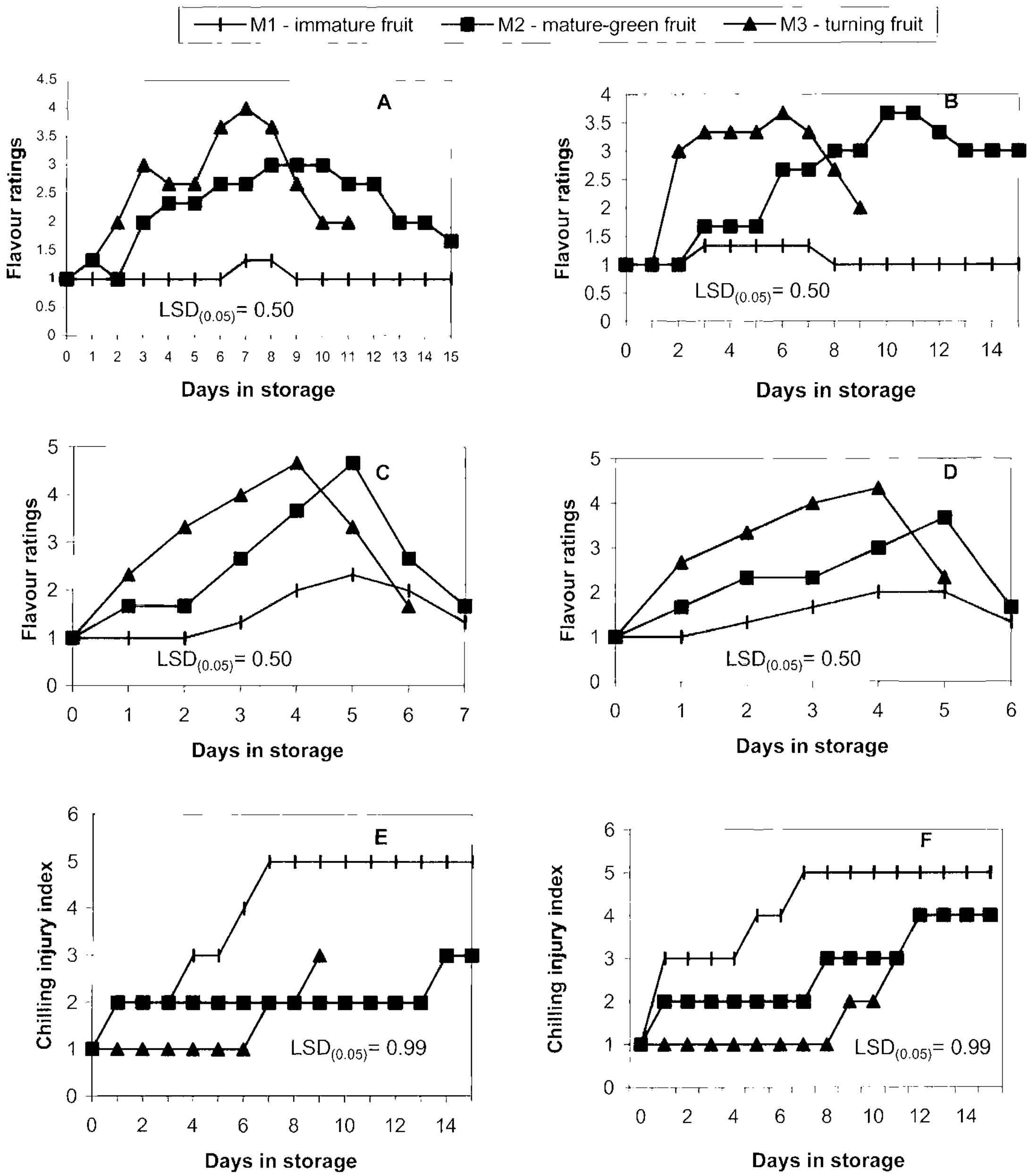

Figure 4. Changes in the flavour ratings and chilling injury index of chili plums during storage. (A) Fruit stored at 4-5°C, (B) fruit stored at 9-10°C, (C.) fruit stored at 20-21°C, (D) fruit stored at 30-31°C, (E) fruit stored at 4-5°C and (F) fruit stored at 9-10°C. Levels of significance were ($P<0.05$) and ($P<0.001$) for flavour and chilling injury respectively.

Table 1. Interaction effects of storage duration x temperature x maturity on decay incidence in chili plums stored at 20-21°C and 30-31°C for 8 days.

Parameter	Storage period Days)	Temperature (°C)					
		20 – 21			30 – 31		
		M1	M2	M3	M1	M2	M3
Decay (%)	4	0	0	13.33ab	0	20.00bc	13.33ab
	5	0	0	13.33ab	6.70a	20.00bc	26.70c
	6	13.33ab	13.33ab	40.00d	53.30e	73.30f	86.70g
	7	46.70de	73.30f	86.70g	100h	100h	100h
	8	100h	100h	100h	100h	100h	100h
$LSD_{(0.05)}$				11.37			

[Y] Means followed by the same letter(s) are not significantly different ($P<0.05$).
M1 = immature fruit, M2 = mature-green fruit and M3 = turning fruit.

Table 2. Interaction effects of storage duration x temperature x maturity on decay incidence in chili plum fruits stored at 9-10°C and 20-21°C, respectively.

Parameter	Storage period (Days)	Temperature (°C)							
		9 - 10		20 - 21					
		M5	M6	M1	M2	M3	M4	M5	M6
Decay (%)	2	0	0	0	0	0	0	0	16.67a
	3	16.67a	100f	0	0	0	0	33.33b	100f
	4	16.67a	100f	0	0	0	0	33.33b	100f
	5	16.67a	100f	0	0	0	0	60.00d	100f
	6	62.33d	100f	0	46.67c	26.67ab	46.67c	86.67e	100f
	7	100f	100f	100f	100f	100f	100 f	100 f	100f
$LSD_{(0.05)}$					13.17				

[Y] Means followed by the same letter(s) are not significantly different ($P<0.05$).
M1 = very immature fruit, M2 = immature fruit, M3 = mature-green fruit
M4 = turning fruit, M5 = half-ripe fruit and M6 = full-ripe fruit.