

## TEMPERATURE-RELATED CHANGES IN RESPIRATION AND $Q_{10}$ COEFFICIENT OF GUAVA

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**ABSTRACT:** Guava (*Psidium guajava* L.) is a tropical fruit that presents fast post-harvest ripening; therefore it is a very perishable product. Inappropriate storage temperature and retail practices can accelerate fruit quality loss. The objective of this study was to evaluate the respiratory activity (RA), the ethylene production (EP) and  $Q_{10}$  of guava fruit at different storage temperatures. 'Paluma' guava fruits were harvested at maturity stage 1 (dark-green skin) and stored at either 1, 11, 21, 31 or 41°C; RA and EP were determined after 12, 36, 84 and 156 h of storage. RA and EP rates at 1 and 11°C were the lowest - 0.16 and 0.43 mmol CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> and 0.003 and 0.019 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup>, respectively. When guavas were stored at 21°C, a gradual increase occurred in RA and EP, reaching 2.24 mmol CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> and 0.20 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup>, after 156 h of storage. The highest RA and EP were recorded for guavas stored at 31°C. In spite of high RA, guavas stored at 41°C presented EP similar to guavas stored at 11°C, an indicator of heat-stress injury. Considering the 1-11°C range, the mean  $Q_{10}$  value was around 3.0; the  $Q_{10}$  value almost duplicated at 11-21°C range (5.9). At 21-31°C and 31-41°C,  $Q_{10}$  was 1.5 and 0.8, respectively. Knowing  $Q_{10}$ , respiratory variation and ripening behavior in response to different temperatures, fruit storage and retail conditions can be optimized to reduce quality losses.

Key words: *Psidium guajava*, ethylene, ripening

## MUDANÇAS NA RESPIRAÇÃO E NO COEFICIENTE $Q_{10}$ DE GOIABA RELACIONADAS À TEMPERATURA

**RESUMO:** A goiaba (*Psidium guajava* L.) é um fruto tropical que apresenta rápido amadurecimento, o que a torna um produto muito perecível. Temperaturas inapropriadas durante o armazenamento e comercialização podem acelerar a perda da qualidade dos frutos. O objetivo desse trabalho foi avaliar a atividade respiratória (AR), a produção de etileno (PE) e o coeficiente  $Q_{10}$  de goiabas em diferentes temperaturas de armazenamento. Goiabas do cultivar Paluma foram colhidas no estágio 1 de maturação (casca verde escura) e armazenadas a 1, 11, 21, 31 e 41°C. AAR e a PE foram determinadas com 12, 36, 84 e 156 h de armazenamento. As taxas de AR e PE a 1 e 11°C foram as menores, atingindo valores ao redor de 0,16 e 0,43 mmol CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> e 0,003 e 0,019 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup>, respectivamente. Quando as goiabas foram armazenadas a 21°C, observou-se aumento gradual em AR e PE, as quais alcançaram valores de 2,24 mmol CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> e 0,20 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup> após 156 h de armazenamento. As maiores AR e PE foram observadas em goiabas armazenadas a 31°C. Apesar de alta AR, goiabas armazenadas a 41°C tiveram baixa PE, similarmente àquelas armazenadas a 11°C, indicando dano por alta temperatura. Na faixa de 1-11°C, o valor médio de  $Q_{10}$  foi de 3,0, enquanto esse valor quase duplicou na faixa de 11-21°C, atingindo 5,9. O  $Q_{10}$  decresceu nas faixas de 21-31°C e 31-41°C, apresentando valores de 1,5 e 0,8, respectivamente. Conhecendo-se a variação do  $Q_{10}$ , da taxa respiratória e do comportamento do amadurecimento em resposta a diferentes temperaturas, as condições de armazenamento e comercialização dos frutos podem ser otimizadas para reduzir as perdas na qualidade.

Palavras-chave: *Psidium guajava*, amadurecimento, etileno

### INTRODUCTION

Temperature heavily influences metabolic activity of plant tissues and organs, such as fruit (Chitarra & Chitarra, 1990). Metabolic reactions, such as respiration

and ethylene production, are fundamental for fruit ripening, but harmful to fruit conservation. These reactions ordinarily increase with increasing temperature up to 40°C, when ethylene biosynthesis is impaired by heat stress (Eaks, 1978). On the other hand, enzymatic reactions oc-

cur more slowly at low temperatures, extending fruit shelf life (Chitarra & Chitarra, 1990). Low temperatures can cause chilling injuries, but the threshold temperature is specific for each species and depends on the ripening stage (Wang, 1982).

The  $Q_{10}$  coefficient commonly used in postharvest studies regarding the fruit respiratory activity, represents the increase in the rate of a process with a 10°C increase in temperature. Enzymatic and physiological processes are twice to three times faster for each 10°C of temperature increase. However, the range of  $Q_{10}$  can go from 1 to 10 or more (Ting, 1982).

The increase or reduction in fruit respiration can vary with the exposure to temperature. Kader (1985) and Kluge et al. (2002) have reported that  $Q_{10}$  values of some fruits change as function of the considered temperature range. The recommended storage temperature for guava fruit (*Psidium guajava* L.) varies from 8 to 10°C (Carraro & Cunha, 1994; Castro & Sigrist, 1988). In typical, tropical Brazilian climate, guava fruit can easily be exposed to temperatures higher than 10°C during storage and commercialization period, and undergo physiological stress and loss of shelf life and quality. The objective of this study was to evaluate the respiratory activity, ethylene production and  $Q_{10}$  of Paluma guava cultivar at different storage temperatures.

## MATERIAL AND METHODS

**Studied material** - 'Paluma' guava fruits (*Psidium guajava* L.) were harvested at maturity stage 1 in a commercial orchard in Vista Alegre do Alto County, SP Brazil (21°10'S; 48°38'W; 700 m) and transported in a refrigerated truck at 15°C during 4 hours to Piracicaba, SP Brazil. The maturity stage was defined by skin color as a fruit with dark-green skin (Azzolini et al., 2004).

**Temperature treatments** - Seven guava fruits were stored in each temperature-controlled chamber at 1, 11, 21, 31 and 41°C during 156 h.

**Respiration and ethylene measurements** - Respiration rate and ethylene production were determined after 12, 36, 84 and 156 h of storage in each temperature. Guava fruits were enclosed in a 0.45 L hermetic flask during 1 h, then gas samples of 0.001 L were collected from flasks with a gas-tight syringe through a silicone septum, and analyzed in a gas chromatographer model Trace 2000GC equipped with a capillary Porapak, 2 m column set at 100°C with hydrogen as carrier gas, pressure  $10^5$  Pa. Respiration rate and ethylene production were determined by measuring the difference between the initial (when flasks were closed) and the final gas concentration (after 1 h), and expressed as  $\text{mmol CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$  and  $\mu\text{mol C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$ , respectively.  $Q_{10}$  values for respiration were calculated

as the quotient between respiration rates (RR) measured at two different temperatures as follows:

$$Q_{10} = \left( \frac{RR_2}{RR_1} \right)^{\left( \frac{10}{T_2 - T_1} \right)}$$

The  $Q_{10}$  was calculated considering the temperature of fruit surface in each measurement. The fruit temperature (FT) was measured with an infrared thermometer model 4000-4GL positioned at 5 cm from fruit surface and attached to a micrologger model CR23X. In addition,  $\log(\text{RR})$  was plotted against FT:  $\log(\text{RR}) = a \cdot \text{FT} + b$ , being  $Q_{10}$  calculated from the  $a$  coefficient:  $Q_{10} = 10^{(10 \cdot a)}$  (Benkeblia et al., 2000).

After 156 h of storage, guava fruit stored at 1 and 11°C were transferred to 25°C for ripening visual observation. Weight loss was determined by weighing individual fruit before respiration and ethylene analyses. The seven guava fruit stored in each temperature were weighed after 12, 36, 84 and 156 h of storage.

The experiment was arranged in random block design ( $n = 7$ ). Data were analyzed using the ANOVA procedure and the Tukey test ( $\alpha = 0.01; 0.05$ ) was used to compare means.

## RESULTS AND DISCUSSION

Respiratory rates of guavas stored at 1 and 11°C were the lowest (Figure 1a). The respiration in guavas stored at 1°C increased in the first 36 h, reaching a stable level between 36 and 84 h, and increasing again after 156 h of storage, reaching  $0.16 \text{ mmol CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ . After an initial increase in the respiratory rate, fruit stored at 11°C presented stable respiration until the end of storage period, values varying around  $0.4 \text{ mmol CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ .

Ethylene production in guavas stored at 1 and 11°C was very low -  $0.003$  and  $0.019 \mu\text{mol C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$  after 84 h of storage, respectively, decreasing to  $0.001$  and  $0.007 \mu\text{mol C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$  thereafter, respectively (Figure 1b). Although low ethylene levels were measured in fruit stored at those temperatures, this plant gaseous hormone is biologically active in trace amounts, being active in concentrations of  $0.01 \mu\text{L L}^{-1}$  (Abeles et al., 1992). Since guavas stored at 1 and 11°C produced very low ethylene, there was no progress of ripening during storage, as confirmed by visual evaluation after 156 h of storage (Figure 2).

In fact, guavas stored at 1 and 11°C exhibited green skin with non-significant alteration of pulp color (Figure 2). Even after 4 days at 25°C, those fruits did not develop the typical, ripe-fruit skin and pulp color (data not shown). Since 11°C is the recommended storage temperature, it was expected that guavas stored at this condition would complete ripening when transferred to higher temperatures. However the fruits did not ripen, possibly

because of the maturity stage in which they were harvested. This can indicate a physiological disturbance caused by low temperature exposure on underlying processes that trigger fruit ripening. Prasanna et al. (2000) reported that pulp color, texture, taste and flavor of ripe custard apples held at 25 and 20°C were superior when compared with those stored at 10°C, which did not normally ripen.

The failure in ripening is a common symptom of chilling injury in tropical fruit (Couey, 1982). Temperatures below 10°C are generally responsible for cold damages in chilling-sensitive tropical fruits, as guavas. As a matter of fact, Osman & Ayub (1998) verified that guavas stored at 3°C did not ripen satisfactorily, and that was related to chilling injury. According to Kader (1985), the ideal storage temperature for those fruits can vary from 10 to 15°C, depending on species and maturity stage. Physical change of membranes, from a flexible, liquid-crystalline to a solid-gel structure, is the primary response in chilled fruit. Secondary responses include decrease in the rate of mitochondrial oxidative activity as well as in-

creasing activation energy of membrane-associated enzymes until a complete disorganization of cellular structure (Wang, 1982).

When guavas were stored at 21°C, the respiratory activity and ethylene production gradually increased, reaching 2.24 mmol CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> and 0.20 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup> after 156 h of storage respectively, (Figure 1). Cavalini (2004) also observed gradual increase in respiration and ethylene production in 'Paluma' guavas harvested at maturity stage 2 (light-green skin) and stored at 25°C, rates being similar to those reported herein (Figure 1). After 156 h of storage at 21°C, guavas were visually ripe, exhibiting a complete yellow skin and red pulp (Figure 2).

The results are in accordance to those reported by Akamine & Goo (1979) for *Psidium* cultivars, reaching maximum mean values around 75 mL CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> (3 mmol CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>) and 4 μL C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup> (0.16 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup>). However, the fruit did not show the climacteric behavior pattern found by Akamine & Goo (1979) in any storage temperature. Guava fruit had same initial quality, and were all at the same maturity stage, i.e. dark-green stage (Azzolini et al., 2004), which excludes those influences on ripening behavior of 'Paluma' guava fruit. Therefore, the climacteric or non-climacteric behavior of guava fruit should be clarified in further studies when an intermediate ripening behavior could be proposed, based on a systemic evaluation of postharvest fruit characteristics in addition to respiration and ethylene production.

The highest respiratory rates were recorded for guavas stored at 31 and 41°C, but respiration rates were always comparatively lower in guavas stored at 41°C (Figure 1a). Ethylene production of guavas stored at 41°C was very low (Figure 1b). In the first 36 h of storage, the ethylene production showed increasing trend, reaching 0.053 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup>. However, after 84 h storage, production of ethylene decreased to 0.010 μmol C<sub>2</sub>H<sub>4</sub> kg<sup>-1</sup> h<sup>-1</sup> a pattern similar to that observed for guavas stored at 11°C (Figure 1b). Similar results were observed for

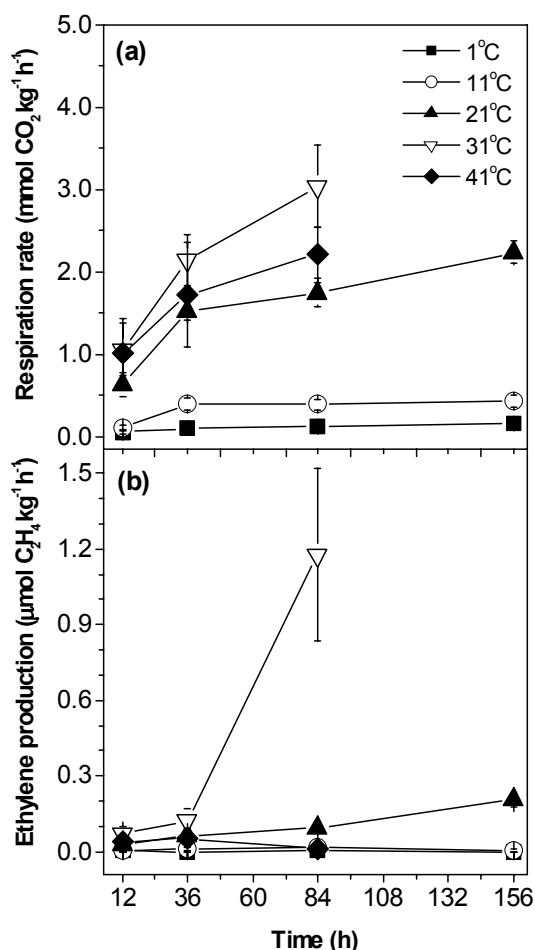


Figure 1 - Changes in respiratory rate (a) and ethylene production (b) of 'Paluma' guavas during storage at different temperature. Each point represents the mean  $\pm$  S.E. (n = 7).



Figure 2 - External and internal appearance of 'Paluma' guavas after 156 h of storage at different temperatures.

kiwi (Antunes & Sfakiotakis, 2000) and apple (Lurie & Klein, 1990), in which high temperature stress decreased ripening and ethylene production, increasing respiration rate.

In spite of high respiratory rates, guavas stored at 31 and 41°C did not show normal ripening during storage period, retaining greener peel and light pulp color, in comparison to guavas stored at 21°C (Figure 2). High temperatures tend to disrupt physiological processes by thermal denaturation of enzymes, and perhaps alteration of important cellular and sub-cellular structures (Ting, 1982). According to Paull & Chen (2000), cell wall degrading enzymes and ethylene production are frequently the most disrupted processes. Failure of fruit to ripe at high temperatures has been attributed to the reduction of ethylene biosynthesis (Eaks, 1978).

The stress resulting from high temperature appears to inhibit 1-aminocyclopropane-1-carboxylate oxidase (ACC oxidase) more than 1-aminocyclopropane-1-carboxylate synthase (ACC synthase) (Yu et al., 1980). Apelbaum et al. (1981) proposed that high temperatures cause impairment of ethylene production by disturbing cellular membranes, resulting in inhibition of the membrane-associated ACC oxidase. In apple and tomato, Yu et al. (1980) and Atta Aly (1992) reported that temperatures of 35-38°C caused endogenous ACC to accumulate concomitantly with the decrease in ethylene. Therefore, the lower ethylene production of guavas stored at 41°C was probably caused by heat-damage, that is, this temperature exceeds the threshold temperature for heat injury.

Fruits stored at 31°C and 41°C presented incidence of anthracnosis, a disease caused by *Colletotrichum gloeosporioides* (Penz) Penz & Sacc. (Piccinin & Pascholati, 1997). The highest incidence of this disease in guavas stored at 31°C can be explained by the fact that 30°C is the optimum temperature for the development of *Colletotrichum*, (Piccinin & Pascholati, 1997). Therefore, the high ethylene production ( $1.17 \mu\text{mol C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$ ), recorded at 84 h after storing guavas at 31°C (Figure 1b), was probably caused by fungi presence. To avoid the interference of fungus respiration, fruit respiration and ethylene production were not measured after 84 h both at 31 and 41°C.

Guavas stored at 1°C and 11°C as well as those stored at 21°C and 31°C had 1.3% and 2.4% weight loss, respectively (Figure 3). These losses were very low and did not cause any visual depreciation. On the other hand guavas stored at 41°C had 6.7% weight loss, after 84 h. In fact, turning visually smaller than fruits of the other groups after 156 h storage (Figure 2).

Regarding  $Q_{10}$  values, significant changes were related to temperature range (Table 1). At the 1-11°C range, mean  $Q_{10} = 3.0$ ; at 11-21°C range this value almost

duplicated, ( $Q_{10} = 5.9$ ). The increase of respiration rate depends on temperature range, being the highest  $Q_{10}$  values found at 11-21°C range ( $P < 0.01$ ) (Table 1). Considering that respiration increases two to three times for every 10°C in temperature rise (Ting, 1982), discretion is needed when referring to guava fruit. Only at 1-11°C range the  $Q_{10}$  values lied between two and three. One possible consequence of misleading  $Q_{10}$  values would be the reduction in shelf life conservation, once the deterioration rate would be twice as fast as expected.

At 11-21°C,  $Q_{10} = 5.9$ . It is thus possible to foresee that the respiratory rate of guavas stored, as recommended (i.e. around 11°C), would increase 6 times when transferring fruits to higher temperatures (i.e. around 21°C), similar to those found at market stands. This fact helps to understand why guava is considered a very perishable fruit. At higher temperature ranges - 21-31°C and 31-41°C -  $Q_{10}$  values decreased to 1.5 and 0.8, respectively (Table 1). Occurrence of physiological damage at 41°C is evidenced by records of  $Q_{10}$  smaller than those observed at 31-41°C range.

According to Larcher (2000),  $Q_{10}$  values are high at lower temperatures because in such conditions biochemical reaction are limited by low enzymatic activity. At high temperatures, the  $Q_{10}$  values are low because in such conditions physical processes, e.g. gaseous diffusion, limit the speed of the reactions. Regarding  $Q_{10}$  values within each temperature range, there were no significant ( $P < 0.05$ ) changes during the storage period, except at 11-21°C range (Table 1). In this condition, the highest  $Q_{10}$  values were observed after 12 h of storage.

Benkeblia et al. (2000) suggested respiration rates increase linearly with increasing temperature (dotted lines in Figure 4). However, this behavior did not happen when fruit was damaged by heating, as occurred at 41°C (Figure 4). This fact probably happens when broad tempera-

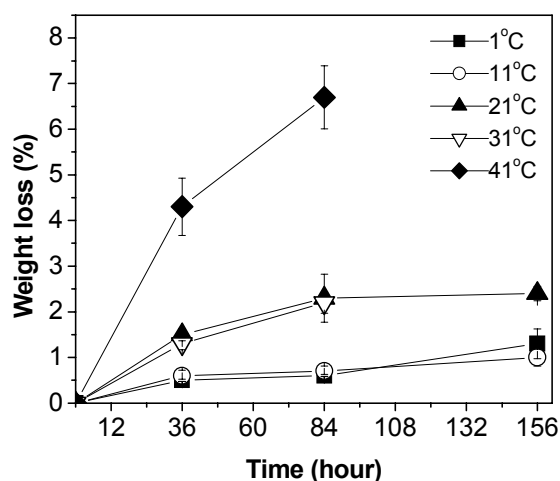


Figure 3 - Changes in weight loss of 'Paluma' guavas during storage at different temperatures. Each point represents the mean value  $\pm$  S.E. ( $n = 7$ ).

ture ranges (i.e. 40°C) are evaluated. The estimation of  $Q_{10}$ , by the linear regression approach leads to lower values in comparison to the mean  $Q_{10}$  value of each evaluation time (Table 1 and Figure 4). Also higher standard errors were observed when  $Q_{10}$  was calculated by the linear regression technique (Table 1 and Figure 4).

Once the visual damage (i.e. fruit did not ripe when transferred to room temperature) was noticed in guavas stored at 11°C and 1°C after 156 h of storage, it is fair to infer that 'Paluma' guava, harvested in stage 1,

can be stored at temperatures between 11 and 21°C instead of the general guava recommendation of storage between 8 and 10°C (Carraro & Cunha, 1994; Castro & Sigrist, 1988). However, further studies are needed to define the optimum temperature to refrigerated conservation of guava fruit, which probably varies according to maturity stage, cultivar, and storage time. Knowing  $Q_{10}$ , respiratory variation and ripening behavior in response to different temperatures, fruit storage and retail conditions can be optimized to reduce quality losses.

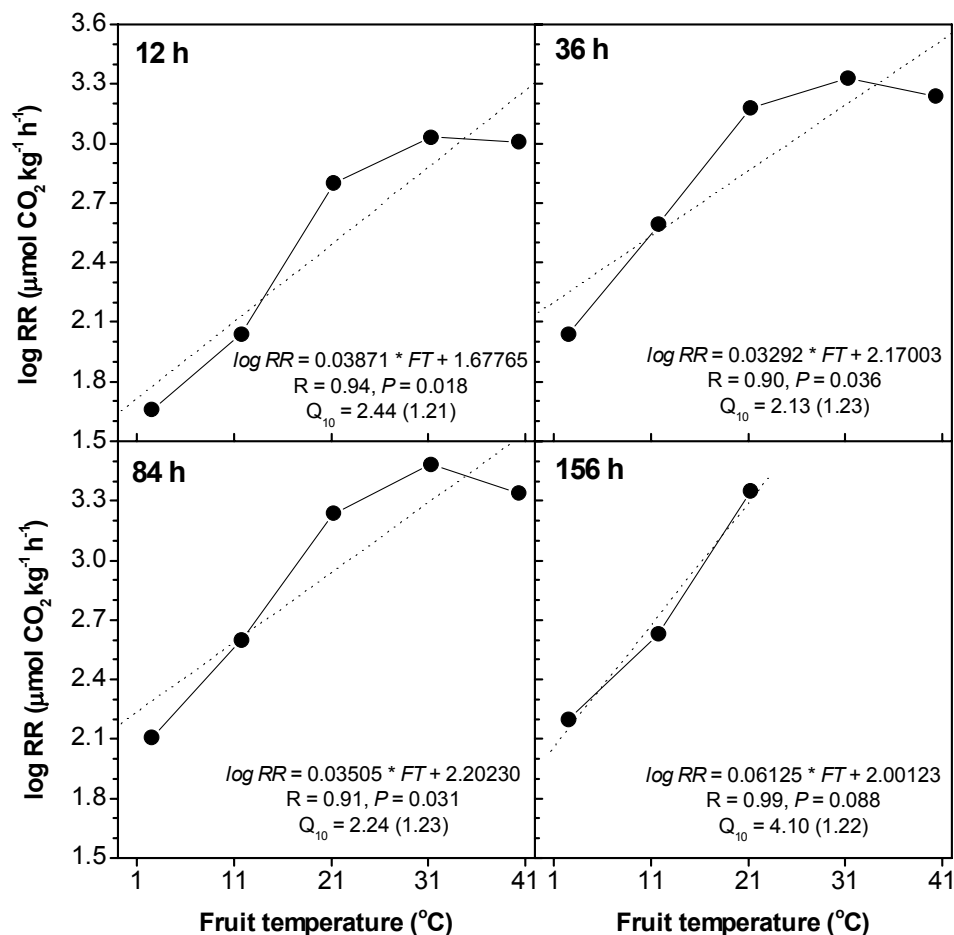


Figure 4 - Respiratory rate (RR) as a function of fruit temperature (FT) at varying storage period and temperature. Dotted lines represent regression lines. Each point represents the mean value of seven replications.

Table 1 -  $Q_{10}$  values\* of 'Paluma' guavas at different temperature ranges.

Time of storage (h)	Storage temperature range				Mean
	1-11°C	11-21°C	21-31°C	31-41°C	
12	2.2 ± 0.3	8.2 ± 1.1	1.4 ± 0.3	0.7 ± 0.2	3.1 ± 0.6
36	3.4 ± 0.3	5.0 ± 0.5	1.4 ± 0.1	0.7 ± 0.2	2.6 ± 0.4
84	3.5 ± 0.3	4.8 ± 0.3	1.6 ± 0.2	0.9 ± 0.3	2.7 ± 0.3
156	2.8 ± 0.3	5.8 ± 0.7	---	---	4.3 ± 0.6
Mean	3.0 ± 0.2	5.9 ± 0.4	1.5 ± 0.2	0.8 ± 0.1	

\*n=7, ± SE

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